Sewage Works Journal

Published by

Federation of Sewage Works Associations

Lancaster, Pa.

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Plant Operation

THE DEVELOPMENT OF THE ACTIVATED SLUDGE METHOD OF SEWAGE TREATMENT *

By Samuel A. Greeley

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General Statement

The development of the activated sludge method of sewage treatment during the last thirty years has been an effort by designers to accomplish satisfactory operation in all the parts of the problem including the following major steps:

a. Preliminary Treatment
b. Aeration
c. Final Clarification
d. Return of Sludge
e. Sludge Disposal

Engineers first applied aeration to sewage treatment in the early part of the decade 1910 to 1920. Black and Phelps in New York and Clark at the Lawrence Testing Station of the Massachusetts State Department of Public Health were early workers.

The publication in 1914 of the classic papers by Ardern and Lockett launched aeration as known today by the term "activated sludge." The first American patent was dated November 20, 1917.

The first large plants placed in operation were at Houston (1916), Milwaukee (1920), Pasadena (1924), and Indianapolis (1926). Many parts of the design have had to be developed by painstaking operating experience, often on a large scale. Gradually, costs have been reduced and operation stabilized. Some problems remain, however. The development of design for satisfactory operation is the viewpoint of this discussion.

Principal Steps in the Method

The principal steps in the activated sludge treatment of sewage comprise the following:

(a) Preliminary treatment
  Grit removal
  Screening
  Scum removal
  Sedimentation

* A special contribution, originally intended for presentation in the technical program of the Eighteenth Annual Meeting and Sixth Annual Convention of the Federation, since postponed.

(b) Aeration with activated sludge
Displacement period
Shape of aeration tanks
Aeration facilities
Return sludge facilities
(c) Final sedimentation tanks
(d) Sludge disposal facilities

These steps and the structures required to provide for them are important in the design of an activated sludge plant. Much has been learned regarding their effect on operation since the first experiences with this method of treatment.

Effect of Sewage Characteristics

The characteristics of both the raw and applied sewage are very important in the design of an activated sludge plant. Such characteristics as result from the age, the strength and the temperature of the sewage are pertinent. Sewages high in organic or volatile matter, with relatively high temperatures and somewhat aged, have proved to be more difficult to treat by the activated sludge method than relatively weak, cool, fresh sewages. Sharp variations in either the quantity or character of the sewage must also be considered. No activated sludge plant should be placed in operation unless the design has been carefully related to the tributary industrial sewages.

Conventional Design

From the experiences of the past some more or less standard or conventional bases of design have emerged. These are described in this section and departures to meet special conditions or by individual designers are discussed in a later section.

Preliminary treatment includes the removal and disposal of coarse floating material (screenings), grit, scum, and suspended solids. Coarse bar screens or racks are generally included with a clear spacing of about one inch. With combined sewers grit chambers are needed. Scum is generally caught in and removed from the sedimentation tanks. Preaeration for a short period to induce scum flotation has occasionally been included.

Various amounts of preliminary sedimentation have been provided. With weak sewages, a displacement period of about one hour has been used. With stronger sewages, the period has been increased up to as much as three hours. An earlier consideration was to reduce the concentration of suspended solids and of B.O.D. entering the aeration tanks to about 100 p.p.m. and 150 p.p.m., respectively. Fine screens have been used in lieu of sedimentation tanks in some of the early designs.

While the early designs of aeration tanks were narrow and shallow, conventional design has developed into tanks fifteen feet deep and twenty-five to thirty feet wide. The construction cost is thus reduced.

Porous plates, for introducing the air in fine bubbles, are placed in rows of containers along one side of each tank. The quantity of air per square foot of plate area is ordinarily limited to one and one-half to three cubic feet per minute. The air is carefully filtered and cleaned.

The conventional aeration period, by displacement, has come to be considered as six hours based on 125 per cent of the average sewage flow to provide for return sludge. In some designs a minimum period of three hours at maximum rates of flow and of return sludge is considered to be controlling. There are, however, departures, generally toward shorter periods, which are sometimes used and the present tendency is to use a somewhat shorter period.

Final clarification or sedimentation tanks are now generally designed to provide a depth of twelve to fifteen feet and an area to provide a settling rate, based on the mixed liquor, of 1,000, more or less, gallons per square foot per 24 hours. This results in a displacement period of about two hours, which is longer than suggested in the early days. Sludge is withdrawn by mechanical equipment and pumps, the sludge hoppers being first at the inlet end and recently, in some designs, at the end opposite the inlet.

Return sludge facilities to return twenty-five per cent of the sewage flow, were provided in early designs; but this is greater now. In some designs, return sludge pumps have a capacity for some fifty per cent or more of the sewage flow.

Sludge disposal with activated sludge has proven to be difficult. Present day conventional designs comprise digestion in separate heated tanks. Capacities up to five cubic feet per capita are not out-of-line for normal conditions.

Good design should include ample facilities for flexibility in operation to meet unforeseen conditions.

Loading Yardsticks

Loading yardsticks include the following, among others:

a. The pounds of B.O.D. applied to the aeration tanks per 1,000 cubic feet of tank capacity.
b. The pounds of B.O.D. applied per 1,000 cubic feet of air supplied or 1,000 cubic feet of air supplied per pound of applied B.O.D.
c. The parts per million of suspended solids in the mixed liquor in the aeration tanks.

With average domestic sewage a conventional load is twenty-five to thirty pounds of applied B.O.D. per 1,000 cubic feet of tank; but under some conditions much higher loads have been attained. Some records from plant operations are as follows:

Plant	Year	Average Pounds B.O.D. Applied per 1,000 Cu. Ft. Aeration Tank Volume
Chicago, North Side	1941	27.7
Chicago, S.W. Side	1941	18.0
Cleveland, Ohio (East)	1941	13.6
Gary, Indiana	1941	26.2
Indianapolis, Ind.	1940	25.2
Pasadena, Calif.	1942	26.4
Peoria, Ill.	1941	29.9
Springfield, Ill.	1941	20.0
Wards Island, N. Y.	1940	38.4

The quantity of air used, expressed as the pounds of B.O.D. per 1,000 cubic feet of air, with normal sewage, ranges from one to two pounds as shown by the following plant operating data:

Plant	Year	Average Pounds B.O.D. per 1,000 Cu. Ft. of Air
Chicago, North Side	1941	2.68
Chicago, S.W. Side	1941	1.08
Cleveland, Ohio (East)	1941	0.67
Gary, Ind.	1941	1.59
Indianapolis, Ind.	1940	1.12
Pasadena, Calif.	1942	0.72
Peoria, Ill.	1941	1.13
Springfield, Ill.	1941	1.25
Wards Island, N. Y.	1940	2.15

Practice and opinion as to the suspended solids in the mixed liquor vary, the general range being from 1,500 to 2,000 parts per million. The proper quantity of return sludge and of suspended solids in the mixed liquor will change from time to time in a plant, however. Thus, the return sludge is one of the important operations in an activated sludge plant. The present tendency is toward lower concentrations, say 1,000 to 1,500 parts per million.

Return Sludge Procedure

In the early designs, the return sludge was introduced into the sewage entering the aeration tanks. At Pasadena sludge reaeration is practiced but not at Milwaukee. Another departure from early designs, developed principally at New York City in recent designs, provides facilities for introducing the sewage in steps at several points in the aeration tanks so that the optimum condition of the sludge and the effectiveness of its action with the sewage can be maintained. The object is to stabilize the process and to accomplish economy in the use of air and in the size of aeration tanks. Such flexibility is a desirable feature. Its use depends to a considerable extent on the character of the sewage and the degree of treatment. With weak sewage, such as that at the North Side plant of The Sanitary District of Chicago, this extent of flexibility does not appear to be needed. Where sludge is reaerated the period is some eighteen to twenty-four hours.

Developments Since First Designs

The first large activated sludge plants in this country were built at Houston, Milwaukee and Pasadena. The contrast between these early designs and present practice is illustrated by the old and new plants at Milwaukee and the recent designs of extensions at Pasadena.

The original plant at Pasadena had fine screens for preliminary treatment, eighteen aeration tanks and five sludge reaeration tanks, with ridge and furrow aeration plate arrangements. Each aeration tank was 67.5 feet long and 10 feet wide, with a liquid depth of 15 feet over the plates. The new plans provide for preliminary sedimentation and three aeration tanks. The aeration tanks are each 210 feet long (total travel) and 32 feet wide, with a liquid depth of 15 feet. Facilities for progressive introduction of sewage are not included in the recent Pasadena plans, but are provided in the plans of the Hunts Point plant in New York City. Based on a study of operating results, it was estimated that the new tanks would require 1.0 cubic foot of air per gallon of sewage as compared with 1.5 cubic feet for the old tanks. In addition, the construction cost per cubic foot of effective tank volume was estimated to be less.

Departure from Conventional Design

A number of departures from so-called conventional design have been proposed and built. Among these are the following:

a. Mechanical aerating devices instead of diffused air, such as submerged paddles, surface brushes and rapidly revolving wheels.
b. Locating the aeration plates or tubes well above the floor in an effort to reduce the pressure to which the air must be compressed. This has not been generally accepted.
c. Stepped aeration as described above.
d. Short-period aeration, which results in a lower degree of treatment but maintains reasonably stable operation.

The development of short-period aeration has been advanced by experiments and practice in New York City at the Wards Island and other large plants under the direction of Gould, Donaldson, Setter, Edwards and others. In Chicago, also, under the direction of Pearse and Mohlman, both experimentally and in actual operation at the North Side plant, short-period aeration has been developed.

In Pasadena, a round aeration and final sedimentation tank combined in one structure has been tried. The aeration is accomplished in an annular tank around the periphery and the enclosed circular space is used for sedimentation.

Application to Various Degrees of Treatment

A useful development of the activated sludge method of sewage treatment is its application to various degrees of treatment. The test-

ing station at Decatur and later the full scale plant showed that relatively good clarification could be accomplished with thirty to forty per cent reduction of B.O.D. when the aeration period was not much over one hour. Setter's work at Wards Island and some full scale operating results indicate reductions of B.O.D. of seventy-five per cent or more with aeration periods approaching two hours, more or less, with generally stable operation. The use of short-period aeration obviously depends on the needs of the receiving waterway. It seems clear, however, that the aeration method of sewage treatment is applicable for some sewages to varying degrees of treatment. The reports of Setter's work are summarized as follows:

Period	Length of Study (Months)	Displacement Period in Aeration Tank (Hours)	Susp. Sol. in Aeration Tanks (P.p.m.)	Per Cent Removal (Final Set. Tk. Effl.)		Air Supplied (Cu. Ft. per Gal.)
				B.O.D.	Susp. Sol.	
1	2.5	4–5	385	77.2	85.7	0.41
2	2.5	2–2.5	625	69.8	83.2	0.36
3	0.5	2–2.5	600	67.0	87.7	0.33
4	2.5	4–5	580	76.6	87.5	0.36
5	2.75	2–2.5	635	71.0	83.6	0.32
6	1.25	2–2.5	365	69.9	86.5	0.30
7	1.0	2–2.5	480	70.0	83.6	0.38
8	1.0	2–2.5	500	67.2	82.0	0.37

Operating Disturbances

The principal operating disturbance is in the behavior of the sludge. This trouble is generally referred to as bulking sludge. There is no conclusive explanation of the cause nor any preferred method for correcting it. One likely factor is the character and condition of the sewage. At Springfield, Ill., during long protracted dry spells, the sewage becomes more concentrated and the time of travel to the treatment plant and into the aeration tank is increased. There is a change in the relation of fixed to volatile solids and the condition of the organic matter is altered. At these times, there is a tendency toward bulking sludge and watchful operation is required. When rainy weather sets in, the operation is much less likely to be disturbed.

Sudden unexpected increases in the strength of the sewage tend to disturb operation, especially if the organic matter is sharply increased, perhaps with carbonaceous material. Some suggested causes of sludge bulking are referred to by Keefer, as follows:

1. Causes associated with the character of the raw sewage:
   a. Septic (or aged) sewage
   b. Excessive organic load
   c. Low inorganic content

d. Presence of trade wastes
e. Presence of mineral oil
f. High fat content
g. High iron content
h. Abnormal pH value
i. Low temperature
j. Greatly fluctuating sewage flow
k. Presence of hydrogen sulfide
l. Excessive carbonaceous content.

2. Causes associated with the operation of the aeration tanks:
a. Underaeration
b. Overaeration
c. Incorrect aeration period
d. Excess suspended solid content
e. Absence of dissolved oxygen
f. Poor mixture of activated sludge and sewage
g. Retarded biological activity
h. Short-circuiting through aerators
i. Excessive growths of filamentous organisms.

3. Causes associated with the operation of the final sedimentation tanks:
a. Maintaining excessive depth of sludge
b. Permitting sludge to become septic:
Production of carbon dioxide
c. Production of nitrogen gas in a highly nitrified effluent.

Among the methods of avoiding operating disturbances are careful control of the dissolved oxygen in the system and of the suspended solids balance. Erratic or unskilled control of the withdrawal of excess sludge will lead to losses of suspended solids in the effluent. Dissolved oxygen should be maintained in the aeration process with a concentration in the effluent up to several parts per million. If the effluent contains relatively high nitrates, then the sludge index is low, the sludge settles well and disturbances are unlikely. But, generally speaking, it is not sufficiently necessary to produce nitrates to justify the higher cost of operation. On the other hand, if the dissolved oxygen, say at halfway aeration, is very low or absent, operating disturbances are most likely.

Obvious precautions are to increase the quantity of air and to change the concentration of solids in the aeration tanks, generally downward, but these steps do not always correct the trouble. There are still some unexplained factors in operating disturbances, such as bulking sludge, and their control.

Operating Routine and Control

In general, the operating routine of an activated sludge plant is not complicated, but often its control is difficult. The balance is delicate.

The essential operations to be controlled are the following:

a. Return sludge pumps
b. Waste sludge facilities
c. Air supply
d. Points of introducing sewage if stepped aeration is provided.

Control tests are needed and these are somewhat different from tests made to show the results of operation. It is necessary to have frequent and immediate results and hourly tests sometimes are made. One of the most informative is the dissolved oxygen test. If there is enough air with a proper solids balance to supply five or six parts per million of dissolved oxygen, there is not much danger of disturbances, but this is not economical and good operation with low cost should be directed to a lower dissolved oxygen, say, two parts per million in the effluent.

The control of return and excess or waste sludge which determines, in large measure, the solids in the aeration tanks, involves the sludge index, the ash content of the sludge and the dissolved oxygen. Quick tests to show changes in the concentration of suspended solids are used. Some operators use quiescent settling in graduated cylinders and others centrifuges of various design. The application of these tests to the control of operation differs in accordance with local conditions and the operators' experience with them. Thus, there is a great difference in the operating control of the North Side plant in Chicago with a weak domestic sewage and of the Southwest Side plant where industrial wastes are present, resulting in a low ash content and a sewage of varying strength.

In the early days at Milwaukee, when operating routines and controls were not so well understood, a miniature plant was kept in operation under continuous observation and frequent test, from which the operation of the full scale plant was largely controlled.

Power Requirements and Facilities

The amount of power at an activated sludge plant depends largely on the quantity of air to be provided. A round unit quality of air under normal conditions is one cubic foot per gallon of sewage, but in some plants with strong sewages and where the excess sludge is sold for fertilizer, as much as one and one-half cubic foot per gallon is used.

In a more or less conventional plant under normal conditions, with mechanical sludge handling facilities and low-head sewage pumping, the power for air will amount to some fifty to sixty per cent of the total amount of power required. If the excess sludge is disposed of by digestion, producing sludge gas, and this gas is used in gas engines to drive blowers, most of the power for air (say ninety per cent) can be produced in this way. The rest may be purchased or otherwise produced at the treatment plant. As the unit quantity of air is reduced and the extent of treatment limited, as with short-period aeration, the power available from sludge gas tends to become sufficient for the entire operation.

The trend in the development of power facilities is to provide units for economical operation with minimum as well as maximum unit quantities ranging from, say, one-half to one and one-quarter cubic foot per gallon of sewage. Variable speed engines and compressors are useful for this purpose.

Operating Results

The operating results of activated sludge treatment are generally excellent. Removals of suspended solids and B.O.D. in excess of ninety per cent are common. Effluents, under normal conditions, usually contain less than twenty parts per million of these two elements. Developments in the last two decades have resulted in the avoidance (in part) of operating disturbances, a more uniform degree of treatment and lower overall costs.

Many factors influence the results of operation, including the season, the temperature, the activity of industries and others. The characteristics of the effluent of two activated sludge plants for two years are summarized as follows:

Plant and Month	Parts per Million in Effluent			
	Suspended Solids		B.O.D.	
Madison, Wisconsin—1943–1944	1943	1944	1943	1944
January	19	21	23	31
February	17	19	15	24
March	16	14	12	19
April	14	20	16	17
May	—	19	21	24
June	8	34	16	23
July	13	20	19	32
August	11	15	19	30
September	11	13	25	28
October	16	29	27	46
November	25	19	33	41
December	33	18	49	35
Springfield, Ill.—1941–1942	1941	1942	1941	1942
January	13	13	14	16
February	8	12	13	5
March	10	8	17	7
April	5	6	5	3
May	4	7	8	7
June	7	7	8	6
July	6	4	13	4
August	8	7	14	10
September	8	8	13	6
October	8	11	3	18
November	10	8	5	4
December	14	9	12	6

Extent of Use

Since the first large plant was placed in operation in Houston in 1917 there has been a steady increase in the use of the process in pace with the development of the mechanics, with the control of operation and improvements in economies of installation and operation. This is indicated by the following:

Year	No. of Plants in Operation	Approximate Total Rated Capacity (M.g.d.)
1920	6	25
1926	18	175
1930	53	400
1934	78	485
1938	223	1,000
1940	297	1,700

The war has interrupted the recent installation of municipal treatment plants but plans are under way for many large units for postwar construction. Some installations were made using the aeration process, in varying degree, at cantonments and other temporary military establishments.

Unsolved Problems

There is much room for future development of the art of sewage treatment by the aeration or activated sludge method, both in design features and in stabilizing operation. Improved mechanical equipment for cleaning air effectively and economically is indicated. Present methods of air diffusion and efficiency of air use are not fully satisfactory and improved means for restoring the effectiveness of clogged diffusers are needed.

Several variations of final sedimentation tank design are now being given consideration in designs for postwar construction. These are deviations from conventional designs in attempting to overcome the effects of currents on the settling, separation and removal of the relatively light activated sludge. Further improvements to accomplish this removal more economically are indicated.

A better understanding of the actions of the process is resulting in better testing and control procedures to overcome the tendencies to unstable operation, as manifested in the bulking of sludge, that now result from the shocks of sudden changes in the quality or the quantity of the sewage being treated. Such procedures, with some further development, should permit more efficient use of tank capacity and air, with resulting economies.

Summary Statement

The application of the activated sludge process of sewage treatment has had a substantial increase since the first large plant was placed in operation in Houston, Texas, twenty-eight years ago.

The basis of design of a treatment plant must be related to the degree of treatment required by the receiving waterway as well as the characteristics of the sewage to be treated. The temperature, age, strength and sharp variations of these and other factors are important. Adjustments of the displacement period, the return sludge, the solids in the aeration tanks and the quantity of air are adaptable procedures.

Much progress has been made in developing lower construction and operating costs and further improvement may be expected. Testing and control procedures are current and are still being studied, which should result in more stable operation and further economies.

TEN YEARS' OPERATION OF THE WEST MIDDLESEX WORKS AT MOGDEN, ENGLAND *

By C. B. Townend

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By the time this paper is published, the Mogden Works of the West Middlesex Main Drainage project will have been in operation for almost ten years. As very little information has yet been made available on the experience gained at this plant, it was with pleasure that I responded to the invitation of the Federation President to prepare a paper on the subject for the annual convention which was to have been held this year at Toronto. Although that event has had to be cancelled, the main object of interchange of knowledge, which has always been such a feature of our associations on both sides of the Atlantic, remains unchanged and will on this occasion be achieved through the medium of the Journal.

As the subject chosen for the main theme of the Toronto program was "Activated Sludge," this account has been prepared primarily from that point of view.

We, in West Middlesex, are proud and honored to have as a colleague, Mr. William T. Lockett, Chief Chemist to the Department, whose name will be forever coupled with the discovery of the activated sludge process. Since his bottle experiments in the laboratory at Manchester in 1913, he has had the unique experience of witnessing within the short span of 30 years the growth of a process which has achieved phenomenal success throughout the world and which is being adopted on an ever increasing scale wherever sewage treatment is seen at its best, from small units to the largest plants in existence. To Mr. Lockett I am indebted for chemical records of the Mogden plant and for views on the operation of the activated sludge process which will materially enhance the worth of this paper.

Although England was the birthplace of the activated sludge process, it is to America that credit must be given for adopting the process with such enthusiasm and for developing plants of the greatest size, from the courageous pioneering efforts of Milwaukee to the largest-scale examples of Chicago North Side, Cleveland, New York Wards Island, and finally to Chicago South West.

The reasons for the relatively greater increase in activated sludge plants in America as compared with Britain are not far to seek. Following the evolution of sewage purification methods from land irrigation, via the contact bed to the percolating filter, which took place in Britain between 1870 and the end of the century, a most comprehensive

* A special contribution originally prepared for presentation in the technical program of the Eighteenth Annual Meeting and Sixth Annual Convention of the Federation, since postponed.

program of treatment plant construction was carried out in the period from 1890 to the outbreak of the first World War in 1914. So it has come about that in the period between the two wars, while British progress in knowledge, experience and technique continued to advance probably more rapidly than at any other time, the opportunities for application of these advances were much less than in earlier decades. When such opportunity has arisen, full advantage has been taken to introduce new practices of every kind but this has been mainly confined to extensions of existing works which have been found necessary to serve increasing populations of particular towns or districts.

America, on the other hand, after a later start, has made tremendous strides in the past 20 years by being able to build complete plants of most modern design on new sites, unhampered by old works.

Although British plants, in general, are 30 to 40 years old or more, it has not yet been possible for economic reasons to achieve any wide-scale modernization by wholesale scrapping and rebuilding. In this regard, it should be remembered that Britain had to face a formidable uphill task as the result of the first World War when she lost one million of her finest men in killed alone, a rate of loss in proportion to population of more than 40 times that suffered by the United States. Such a handicap has undoubtedly had its effect on the national productive capacity and on the speed with which it has been possible to replace obsolescent plants of all kinds, particularly of services such as sewage disposal which, having been provided so generously in a comparatively recent period, were not so pressing as other problems such as housing.

The great drive in the building industry, however, by which 40 per cent of the entire population of the country was rehoused in the inter-war period, could not be carried out entirely without repercussions on sewage treatment facilities. Some opportunities were created in this way to construct entirely new sewage disposal works, while in other cases it was possible to replace a number of works by one central plant.

Thus in the Greater London area, from 1925 onwards, a very considerable migration of population commenced from the inner districts to enormous new dormitory suburbs which were developed in the outer ring. Of this movement of population, the western part of the County of Middlesex received a predominant share.

According to the Report on the Drainage of Greater London, published by the Ministry of Health in 1934, the total population of 9,000,000 then resident within a 25-mile radius of Charing Cross, was served by over 180 sewage plants. Of this total, however, the central portion with a population of 5,500,000, living in an area comprising the County of London and a number of bordering districts, was dealt with by a main drainage system discharging to two central points only.

With a few exceptions, no co-ordinated schemes existed in the outer areas where the drainage of each borough or urban district was the responsibility of the local authority.

The West Middlesex Project

The difficulties caused by rapid urbanization of Middlesex County in these circumstances proved overwhelming, and the West Middlesex Main Drainage project was authorized by Parliament in 1931 to serve a comprehensive district of 160 square miles, including the complete areas of 15 local authorities which formerly operated 28 separate sewage plants. By this scheme, the whole of these old plants were scrapped and replaced by a new central works at Mogden. The design and construction of the scheme were completed in the 4 years, 1931 to 1935, at a total cost of £5,500,000. Of this amount, £3,250,000 was required for 70 miles of main intercepting sewers which linked up the local systems of each district to the new point of outfall, and £2,000,000 for the plant for sewage purification and sludge disposal.

The rapid growth of population of the district is indicated by the following figures:

Census, 1921	493,000
Date of authorization of scheme, 1931	771,000
Date of commencement of operation, 1935	1,000,000
Mid-1939	1,178,000

At the outbreak of war in September, 1939, the figure was practically 1,200,000 and although this has fluctuated during the years which have followed according to the various events of the war period, particularly by reason of civilian evacuation, destruction of property by bombing, and by the absence of large numbers of men on active service, there have been movements into the area from the center of London and elsewhere with the result that the number of people in the district today is still in the region of 1,170,000.

On this basis, therefore, Mogden ranks among the foremost works in the world and is the largest complete treatment plant outside the United States (Figure 1).

The project was designed to serve an ultimate population of 2,000,000 and for this purpose 100 acres of land were reserved on the Mogden site. Of this area, it was estimated that the ultimate plant would require 70 acres of which about 45 acres have so far been occupied. This site is situated in a residential district which is well developed fairly closely to the Works boundary on all sides.

A further 250 acres were acquired for the purposes of final sludge disposal at a second site, known as Perry Oaks, which is located seven miles away in a country district.

The location of the two works (Figure 2) is an example of what can be achieved by modern processes. By the employment of improved tanks for sedimentation and of the activated sludge process for biological purification, the plant can be built compactly on a relatively small site without interfering with local amenities, and therefore can be situated to accord more fully with major engineering considerations.

The final disposal of sludge can be carried out quite independently by pumping it away into a rural district where land is more readily available and cheaply acquired.

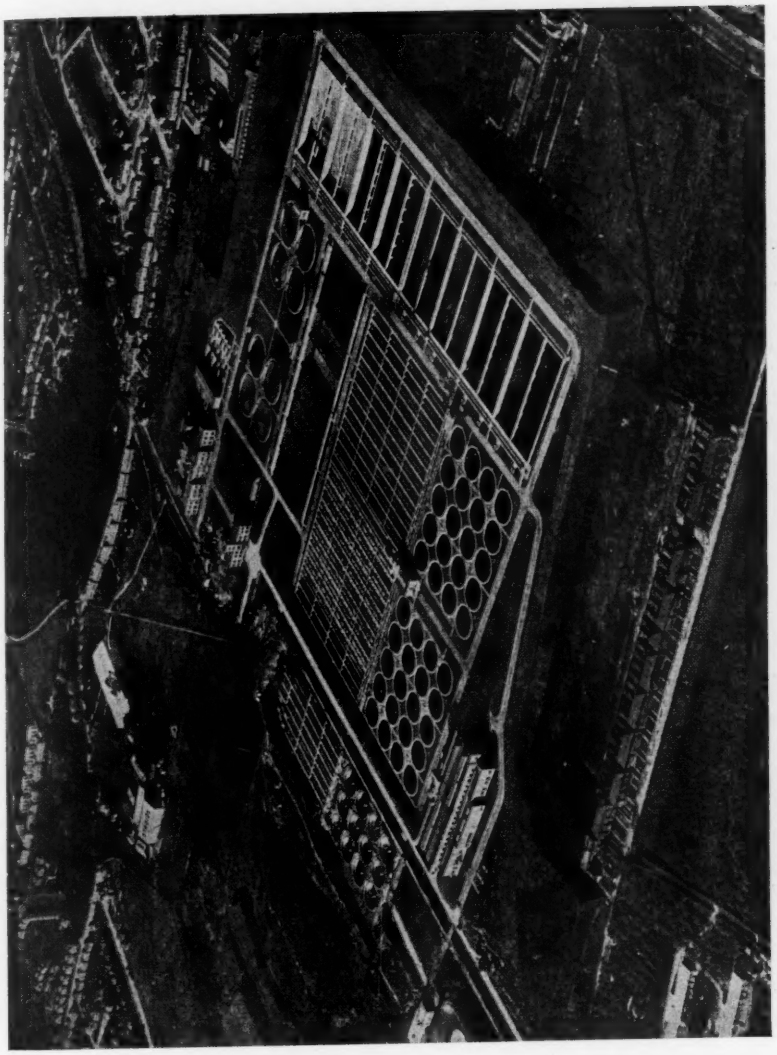

FIGURE 1.—Aerial view of Mogden Works.

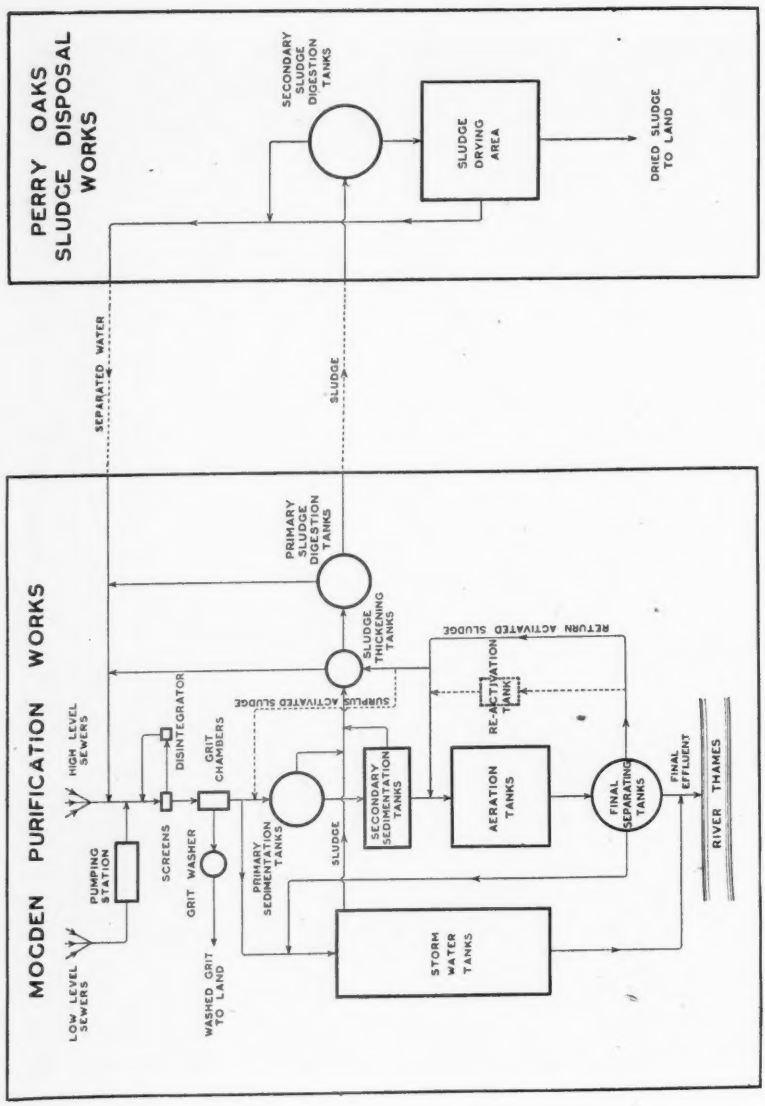

FIGURE 2.—Flow diagram of Mogden and Perry Oaks Works.

The Record of Ten Years

The first diversion of sewage into the new plant, to the extent of about 3 m.g.d., took place on December 14, 1935. Within one week sufficient bacterial energy in the activated sludge tanks had been built up to produce an effluent within the standard required by the river authority of 20 p.p.m. B.O.D. After a pilot run of about 6 weeks' duration, it was decided to commence the main program of sewage diversion from the 28 old works and, by the end of May, the sewage from over 1,000,000 people had been connected to the new system.

This change-over involved about 100 major connections of various sizes but was carried out without serious difficulty. By accumulating a reserve of activated sludge in the reaeration units, the quality of the effluent was maintained continuously at a high standard, even though on occasion the sewage of an additional 100,000 people was connected overnight.

The results which are given in the remainder of this paper are confined to the subsequent period of operation on full load which commenced at the beginning of June, 1936.

In the main, this period of ten years has been one of lively satisfaction in the successful operation of a great venture, but this has been mingled with a sense of frustration at the impossibility of making even further progress in design and operation, or of carrying out research work on a scale which might have represented a greater contribution towards the general pool of knowledge.

In normal times, considerable advances would have been looked for during a ten-year period, but in Britain the past seven years have been dominated by war or the threat of war.

At Mogden, the two years following June, 1936, were no more than sufficient to build up the organization of an entirely new undertaking and to establish plant operations on a sound routine basis. Amid the preoccupations of the period which has supervened, the main problem has been to insure the mere continuance of operation. With operators and staff cut down below what appeared to be the absolute minimum of older men who escaped the clutches of the various Government departments requiring manpower, while those remaining were loaded with additional emergency duties of every conceivable kind, and with the enemy doing his best to make things unpleasant, this has not always been easy. Nevertheless, the plant has never failed to produce a first-class effluent at any time since it was first put into commission.

The main processes employed, of purification by activated sludge, and of sludge disposal by digestion, have proved to be outstandingly successful. At Mogden, these processes are essentially interlocking since the methane gas produced from the digestion plant is ample to provide the power requirements for the supply of compressed air on a generous scale, while the waste heat from the power station, in turn, is more than sufficient for heating the digestion plant.

The main sewers have been constructed large enough to serve the final population and have a total discharging capacity of 700 million U. S. gallons per day.

Most of the districts in the West Middlesex area are sewered on the partially separate system, that is to say, while rain water from roads and paved areas, etc., is discharged directly into streams and river courses by surface water sewers, a certain proportion of rain water is delivered into the foul water sewers from roofs and yards. This addition of rain water is sufficient to increase the flow to the sewage works very considerably in wet weather.

In the treatment of stormwater, there are distinct differences between the practice in Britain and that in America. In Britain, the consumption of water per head of population is very much less than is generally the case in America and sewages in Britain are therefore much stronger. From this fact has arisen the British practice of giving full treatment in the purification plant up to a volume equal to 3 times the dry weather flow and after that, to give good sedimentation in stormwater tanks to the surplus flow over 3 times and up to 6 times the dry weather flow. Above this maximum figure, it is customary to discharge the surplus flow directly into the river, although, as at Mogden, a much larger volume may be given tank treatment.

Despite these differences, the overall protection afforded to the rivers is not dissimilar in the two countries. For instance, in the case of a British dry weather flow of 50 U. S. gallons per capita, full treatment would be given up to 150 gallons, and sedimentation treatment to a further flow from 150 gallons up to 300 gallons per capita. No direct overflow to the river would take place before this dilution of 300 g.p.c. had been reached. This compares fairly closely with an American city having a dry weather flow of say 180 g.p.c., with overflow to the river at 1½ times this rate or 270 g.p.c.

The present minimum dry weather flow at Mogden, on the basis of a monthly average discharge, is 63 million U. S. g.p.d., or 54 gallons per capita. The maximum discharge recorded up to the present time is at the rate of 540 million gallons per day, equal to nearly 9 times the dry weather flow. This maximum rate, however, includes a certain proportion of flood relief water which has been arranged to discharge into the sewers while there is spare sewer capacity available during the early years of operation.

In spite of such a wide variation in flow, it is remarkable how large a proportion of total flow is given complete treatment by activated sludge. For the nine-year period of full operation from June, 1936, the average daily flow was 74.22 million U. S. g.p.d., of which no less than 96.8 per cent, or an average of 71.86 m.g.d., received full purification treatment. The remaining 3.2 per cent, consisting of surplus stormwater, received single stage sedimentation for about 2 hours; no sewage arriving at the Works can be discharged without this minimum

treatment (Figure 3). As the surplus stormwater has a strength well below that of normal sewage, the total pollution load diverted for treatment in stormwater tanks was not more than 1 per cent of the load receiving full treatment.

The protection given to the rivers under these conditions is excellent. A considerable smoothing out of the peak flows is achieved by

FIGURE 3.—Stormwater diversion chamber at Mogden Works.

the size of the contributory district and the system of purification at the Works is such that a very satisfactory effluent is produced at all rates of flow.

SEWAGE CHARACTERISTICS AND POLLUTION LOADS

The West Middlesex sewage is predominantly domestic in character but there is also a considerable proportion of trade waste which is largely organic in origin and mainly derived from yeast factories, breweries, milk distributing centers, jam and other food product factories, etc. From one large brewery, the volume discharged is about 600,000 U. S. g.p.d. with a B.O.D. of about 1,500 p.p.m., while from two

yeast factories, the total volume of waste is 240,000 g.p.d. with a B.O.D. of 6,250 p.p.m. In recent years, there has also been an increasing discharge of waste liquors from gas works and plating plants.

The average B.O.D. load of sewage and trade waste received at Mogden during each of the nine years is given in Table I. The rapid development and increasing activities of the drainage district during the first four years up to the outbreak of war is shown by the steep rise in pollution load between 1936 and 1939, representing an increase of 40 per cent.

TABLE I.—*Raw Sewage Received at Works, 1936 to 1945*

Year Ending March 31	Flow Received (M.g.d. (U. S.))	B.O.D. 5 Days at 18.3° C. (P.p.m.)	B.O.D. Load (Lbs. per Day)	
			Yearly Average	Maximum Month
1936–37 (10 months only)	67.61	295	166,000	170,000
1937–38	65.65	325	177,000	201,000
1938–39	71.18	352	209,000	232,000
1939–40	84.10	329	231,000	264,000
1940–41	72.23	252	152,000	207,000
1941–42	79.33	255	169,000	209,000
1942–43	79.90	276	184,000	188,000
1943–44	70.57	335	197,000	228,000
1944–45	76.27	303	193,000	211,000

The adverse effect of the war is very marked, particularly during the worst period of heavy bombing in 1940 when the load dropped below that of 1936. Since then the recovery continued until 1944 when there was a slight falling off due to the advent of flying bombs and rockets.

It will be noted from the table that the B.O.D. load for the maximum month in any year is normally at an appreciably higher level than the 12 months' average figure. During the years of peace, the pollution load dropped very much during the holiday months of the summer, most particularly in August, when people left the suburban areas in very large numbers. This was invariably followed by a sharp increase in load during the fall, rising to the maximum load of the year during the winter months from November to March or April. This characteristic fluctuation has been almost entirely upset during the war period when variations have been due to entirely different causes.

The highest B.O.D. load recorded during the nine years was 231,000 lbs. per day for 1939–40 with a maximum month of 264,000 lbs. per day in April, 1939. By American standards at 0.167 lbs. per capita, this would represent an average human equivalent population of 1,386,000 for the highest year and 1,584,000 for the maximum month. The actual population in April, 1939, was 1,170,000 but allowing for the summer holiday season and the evacuation in the late months of 1939, the average for the year would not exceed 1,100,000. This would imply an

average trade waste discharge for the year equivalent to a human population of 286,000, rising to a monthly maximum of 414,000.

It is evident, however, that the B.O.D. loading per capita for domestic sewage in Britain is rather less than the American figure, for in 1936, the maximum B.O.D. load in any month did not exceed 0.160 lbs. per head per day inclusive of all the trade waste which was then being discharged. Thus the proportion of trade waste to domestic sewage at Mogden is probably higher than the above figures would indicate.

Under wartime conditions of food shortage and rationing, the B.O.D. load for domestic sewage has dropped considerably. Although trade wastes have definitely increased, the over-all load per capita for 1942–43 was only 0.159 lbs. B.O.D. Assuming an average trade waste discharge with a human equivalent of only 300,000, this would imply that the domestic load had dropped to no more than 0.116 lbs. B.O.D. per capita.

Preliminary Treatment

Of the total volume of sewage arriving at the Works, about 75 per cent is conveyed by gravitation in the high level sewers at a sufficient elevation to pass through the Works without pumping. The remaining 25 per cent of the flow is derived from the Thames Valley low level area, and after gravitating to the pump well at the Works, it is lifted about 50 ft. and discharged into the plant with the incoming high level sewage. Electric power, generated at the Works power station, is used for pumping low level sewage up to a rate of about 3 times the dry weather flow. For higher flows, stormwater pumps driven by diesel engines are employed. The gross pumping capacity is 240 million U. S. g.p.d.

The screening and grit removal plant is divided into six independent units, each with a maximum capacity of about 115 million U. S. g.p.d.; these are brought into operation successively in accordance with the rate of sewage flow by means of hydraulically operated penstocks.

The screens are located above the grit chambers. Each unit is equipped with a coarse rack with 4-inch openings followed by a bar screen of ¾-inch openings. The coarse racks are cleaned by manually operated raking gear, but following the difficulties which have been experienced in keeping pace with the work during times of high flow, it is intended to install mechanically operated rakes as soon as opportunity permits. The bar screens are cleaned by electrically driven rakes discharging their screenings to a macerator, where they are disintegrated in a plant developed from the old stereophagus type of pump, and delivered back into the sewage above the screens.

The shape of the cross section of the grit chambers is based on a parabola, modified in certain respects for constructional reasons. Each grit chamber is followed at its outlet end by a standing-wave Venturi flume (known in America as the Parshall flume) which not only records the flow but also controls the level in the chamber in such a way that, by means of the parabolic section, a velocity of one f.p.s. is maintained

at all flows. Such conditions are independent of the number of chambers in use and can be maintained for all volumes of discharge, from the present minimum night flow to the ultimate maximum storm flow, a range of over 20 to 1. The length of each chamber is 90 ft., giving a detention period of 1½ min.

The deposited grit is removed by suction dredging and, after further washing with effluent in a storage hopper located beneath the screenhouse floor, it is pumped away underground to settling ponds for final disposal. The final product is practically entirely inorganic matter.

The whole of the sewage flow arriving at the Works has to pass through the screens and grit chambers, but following this plant, the volume passing forward for complete treatment is limited to 3 times the dry weather flow. In times of wet weather, surplus volumes in excess of this flow are diverted at an overflow chamber to pass forward for about 2 hours' sedimentation in the stormwater tanks. These tanks have a total capacity of 24 million U. S. gallons which should be ample for the ultimate conditions.

In the treatment of normal sewage, it is customary in Britain to provide for a much longer period of preliminary sedimentation before the activated sludge plant than is the case in America. To a large extent, this is due to the greater variations of flows which are treated in Britain. For instance, at Mogden the total capacity of the preliminary sedimentation tanks is 16.2 million U. S. gallons; this works out at about 6¼ hours detention period on the dry weather flow. At 3 times the dry weather flow, however, this period is reduced to not much over 2 hours, which is more in accord with American practice. It would be possible in dry weather to shut down some of this sedimentation capacity (and to some extent this is done in very hot weather) but in general, it is the British practice to use the full available capacity at all times, thereby giving the maximum protection and relief to the biological purification plant, both by securing some smoothing out of variable strengths and by effecting as much removal of pollution load as possible by simple and cheap methods.

In dry weather, the suspended solids are reduced by sedimentation at Mogden from a figure of between 300 and 350 p.p.m. for the raw sewage to about 60 or 70 p.p.m. for the tank effluent, a reduction of 80 per cent. The average figures for the nine-year period (including all high flows in times of rain) were 237 p.p.m. and 68 p.p.m., respectively, giving a reduction of 71 per cent. During the same period, the B.O.D. reduction was 45 per cent, from an average of 309 p.p.m. to 171 p.p.m., but in certain periods of dry weather, the reduction has been 50 per cent or more from 400 p.p.m. and upwards to 200 p.p.m. or less. These results have been obtained in spite of the additional duty put on to the sedimentation plant in dealing with the surplus activated sludge which is added to the raw sewage just ahead of these tanks. Considerable assistance, however, in reducing the volume of this surplus sludge to a minimum is obtained by retaining as much suspended

matter as possible in the sedimentation tanks before passing the settled effluent to the aeration tanks.

Of the total sedimentation capacity provided, one-third consists of a primary stage of eight circular tanks, each 95 ft. in diameter and 12 ft. in average depth, with central inlet and peripheral weir. The sludge is removed by scrapers operated by a revolving bridge type mechanism.

The remaining two-thirds of the plant consists of a secondary stage of four rectangular tanks where the lighter solids are removed. The tanks are each 200 ft. long by 150 ft. wide by 12 ft. deep, divided by a central wall into two bays. Sludge is removed by one Mieder-type machine, of 75-ft. span, which serves the whole battery of tanks by the use of a transporter carriage.

The Activated Sludge Plant

The aeration tanks at present constructed consist of two batteries, each of six units, with a third battery half completed of three units only, making a total of fifteen units in all. Each unit is of 2,000,000 U. S. gallons capacity, the total capacity of the plant thus being 30,000,000 gallons. The unit consists of four channels in series, each 400 ft. long by 15 ft. wide by 12 ft. deep.

Of the completed batteries, one is arranged for spiral flow operation with two rows of eight-inch diffusers installed on one side of each channel, while the second battery is arranged on the longitudinal ridge and furrow principle with three rows of six-inch diffusers spaced at 5-ft. centers.

The air supply is maintained at a uniform rate throughout the length of the four channels in each unit.

Provision has been made for using up to two aeration units in each battery as sludge reaeration units.

Each of the two batteries of aeration tanks is served by 20 final separating tanks, with an additional 12 tanks for the partially constructed third battery, making 52 tanks in all, with a total capacity of 15,600,000 U.S. gallons. Not more than 40 tanks have yet been placed in commission, and at the present volume of flow in dry weather, this allows an overflow rate of 585 gal. per sq. ft. per day. At the maximum discharge in wet weather, however, the overflow rate may rise to 1,750 gal. per sq. ft. per day.

The final tanks are circular in plan, 60 ft. in diameter, with central inlet and peripheral weir. They have a side water depth of 8 ft. and a conical floor sloping at 30° with the horizontal to a total depth of 25 ft. in the center. Any sludge deposited on the sloping floor is moved continuously towards the center by a rotating-ring type mechanism. It is estimated, however, that a considerable proportion of the sludge does not rely on the machine for its removal as it is drawn towards the outlet by the downward currents set up by the comparatively high volume of sludge returned from the tank.

The design of these final tanks appears to be out of line with the American practice of adopting larger units for plants serving populations of this size. It is the experience in Britain, however, that in the case of final tanks, the best effluent is obtained from the smaller units. In addition to this, from the point of view of the condition of the sludge, it is important to provide for its settlement and removal in the shortest possible time and the smaller tank also has advantages on this score. For these reasons, it was not desired to go beyond a diameter of 60 ft. The results obtained have been extremely satisfactory as may be judged by the low solids in the effluent, and the control of 40 units has not proved in the least troublesome or expensive.

Apart from such differences, the general layout of the activated sludge plant is very similar to the latest American practice. The return sludge pumping station is located in the center of the operating gallery between the two batteries of aeration tanks and the final tanks. The operating gallery consists of a covered basement only, with weatherproof instruments standing in the open on the roof at ground level. Centralized indicating, recording and integrating is provided on a main instrument panel in the return sludge pumping station.

The final effluent is discharged through two tunnels, each 11 ft. diameter, into the River Thames at a point three-quarters of a mile from the Works.

Operation

During the early period of operation after the plant was started up in 1936, the whole policy of procedure was directed towards obtaining a high quality sludge and a superior final effluent. This was completely achieved and the results on the whole were remarkably good. The average B.O.D. of the effluent for the ten months from June, 1936, was 6.0 p.p.m., while seven consecutive monthly averages were consistently below 4.8 p.p.m., with a minimum month of 3.8 p.p.m. For the same ten months, the average figure for nitric nitrogen was 19.5 p.p.m., with a maximum month of 23.8 p.p.m.

Although the air consumption was very reasonable during this period, being not much over 1.0 cu. ft. per U. S. gal., the nitrification process was extended rather further than was absolutely necessary to meet all requirements, and in subsequent years the plant has been operated so as to obtain effluents of rather lower nitrate content.

This modification in procedure, however, has been relatively small, the average figure for nitric nitrogen during nine years being 12.7 p.p.m., with a minimum year of 8.4 p.p.m. The production of well nitrated effluents at Mogden is in sharp contrast with the general trend in America, and elsewhere in Britain, to use non-nitrifying sludges for the purpose of securing more economical operation by a reduction of aeration period and air consumption.

With ample power available at Mogden from internal sources, the question of air supply has not been of sufficient importance to override other considerations. Nevertheless, with the rapidly increasing sewage

load experienced during the early years, economy in the use of power plant and compressors was a factor to be taken into account, and this also applied to the provision of aeration tank capacity. The importance of these factors has been accentuated during the war period, when the minimum use of plant has been necessary to achieve the largest saving in manpower.

The continued production of nitrified effluents in these circumstances has been determined after balancing all the factors involved, and has been achieved with an aeration tank capacity and air supply which compare not unfavorably with most plants using non-nitrifying sludge.

The advantages to be gained by the production of nitrified effluent were claimed by W. T. Lockett in 1937 (1) to be:

1. A comparatively uniformly dense sludge which facilitates plant operation.
2. Freedom from bulking.
3. A nitrified effluent which is relatively much superior for the preservation of good stream and river conditions.
4. Greater capacity for dealing with overloads, *e.g.*, heavy discharges of non-inhibitory trade waste and consequent less liability to produce unsatisfactory effluents.
5. Almost complete freedom from odors when working under adverse conditions which may occasionally arise, *e.g.*, somewhat septic sewage of drought periods.
6. Large reduction in bulk of surplus sludge; also because of vigorous aerobic digestion in the aeration tanks, a reduction in the quantity of dry solids discharged as surplus sludge.
7. A sludge more amenable to dewatering and less liable to cause nuisance if dealt with on land.

These advantages are of outstanding value under Mogden conditions and they have been consistently obtained in practical experience.

One of the outstanding merits of the plant is its remarkable robustness in operation. At times it has not been treated at all kindly, for instance, in an early period, difficulties were caused in the control of the sedimentation tanks by the completing of unfinished work by the contractors, resulting in a septic effluent being passed on to the aeration tanks for prolonged periods. Nevertheless, the activated sludge process stood up to that treatment in an extraordinary manner. With a generous percentage of return sludge containing large quantities of nitrate and dissolved oxygen, the process was protected from harmful effects, and a well conditioned sludge was able to complete the process with scarcely any noticeable effect on the effluent.

A summary of operating data for the nine-year period is given in Table II, while Tables III and IV give details of plant performance and analytical results for each of the years covered. The comments which follow embody opinions on plant operation and explanations of chemical analysis and other matters supplied by Mr. Lockett, whose unri-

TABLE II.—*Summary of Operating Data, 1936 to 1945*

Sewage Flows:

	Million U. S. G.p.d.
Dry weather flow	63.0
Maximum rate of flow received	540
Average flow received	74.22
Average flow treated by activated sludge	71.86
Average flow given sedimentation only (stormwater)	2.36

Activated Sludge Plant Data:

	Number	Hours Detention Period
Aeration units in use for mixed liquor	9.90	6.62
Reaeration units in use for sludge	1.32	0.88
Total	11.22	7.50
Air supply, cu. ft. per min.		48,530
Air per sq. ft. of aeration tank surface, cu. ft. per min.		0.165
Air per gallon, cu. ft.		0.97
Air per lb. B.O.D. removed, cu. ft.		717
Volume of return sludge, per cent of sewage		33.4
Suspended solids in mixed liquor, p.p.m.		2,400
Ratio of return solids to applied solids		34.3
Surplus sludge, m.g.d. (U. S.)		0.92
Surplus sludge, per cent solids		0.82

Analytical Results, P.P.M.:

	Raw Sewage	Settled Sewage	Activated Sludge Effluent	Total Percentage Removed
Oxygen absorption from acid $KMnO_4$ 4 hours at 26.7° C.	80.0	46.5	11.3	—
Ammoniacal nitrogen	37.8	39.2	14.7	—
Albuminoid nitrogen	8.1	4.6	0.85	—
Nitrous nitrogen	—	—	3.0	—
Nitric nitrogen	—	—	12.7	—
Chloride (as chlorine)	103	103	99	—
B.O.D., 5 days at 18.3° C.	309	171	8.3	97.3
Suspended solids	237	68	7	97.1

Number of daily composite samples found putrefactive after incubation, 6 days at 26° C.	None
Number of samples incubated	3141

valled experience with the activated sludge process is reflected in the results obtained.

Comments on Results

Reaeration of Sludge. The practice of reaeration of sludge has been continued throughout the nine years of operation. Generally, one aeration unit of the spiral flow type has been used for this purpose, but during a number of periods, each extending over several months, a second unit, usually one of the ridge and furrow type, has also been used.

Tests have shown that during the reaeration period nitrification continues, and that frequently the ammoniacal nitrogen of the interstitial water of the sludge is entirely removed.

TABLE III.—*Performance of Activated Sludge Plant, 1936 to 1945*

Year Ending March 31	Settled Sewage Treated (M.g.d. (U. S.))	B.O.D. Load (Lbs. per Day)	Aeration Period (Hours)			Air Consumed		Suspended Solids in Mixed Liquor (P.p.m.)	Sludge Index	Per Cent Return Sludge	Ratio Return Solids to Applied Solids	Surplus Sludge	
			Aeration Tank	Reaeration Tank	Total	Cubic Feet per U. S. Gallon	Cubic Feet per Lb. B.O.D. Removed					M.g.d. (U. S.)	Per Cent Solids
1936–37 (10 months only)	64.75	88,500	6.43	0.74	7.17	1.04	788	3850	42	37.1	47.7	0.53	1.25
1937–38	64.27	99,600	6.84	1.06	7.90	1.07	710	2880	56	37.3	42.3	0.82	0.88
1938–39	68.39	114,500	7.21	1.00	8.21	1.06	654	2640	64	35.1	34.2	—	—
1939–40	79.32	105,100	6.66	0.60	7.26	0.93	755	2400	60	30.3	37.1	—	—
1940–41	70.34	79,700*	6.52	0.93	7.45	0.93	887*	2090	62	34.1	33.9	0.82	0.76
1941–42	77.46	98,800	5.82	0.76	6.58	0.85	701	2220	63	31.0	33.2	0.93	0.84
1942–43	76.72	105,500	6.46	0.62	7.08	0.88	680	1960	72	31.3	27.8	1.09	0.79
1943–44	69.94	111,900	6.94	1.30	8.24	1.04	674	1760	85	34.4	24.9	1.07	0.71
1944–45	74.33	114,000	6.72	1.00	7.72	1.00	697	2050	75	32.3	27.5	1.09	0.77
9-Year Average	71.86	102,400	6.62	0.88	7.50	0.97	717	2400	65	33.4	34.3	0.92 (7-Year Average)	0.82 (7-Year Average)

* Plant operation somewhat abnormal owing to war damage to main sewer.

TABLE IV.—*Analytical Results, Activated Sludge Plant, 1936 to 1945*

(Parts per Million)

Year Ending March 31	Oxygen Abs'n., 4 Hours, N/80 $KMnO_4$ at 26.7° C.		Ammoniacal Nitrogen		Albuminoid Nitrogen		Nitrous Nitrogen	Nitric Nitrogen	B.O.D. 5 days at 18.3° C.		Suspended Solids		Incubation Test for Effluent, 6 days at 26° C.	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Effluent	Effluent	Influent	Effluent	Influent	Effluent	Number of Daily Composite Samples Incubated	Number Putrefied After Incubation
1936–37 (10 months only)	42.4	9.6	36.4	6.5	4.3	0.75	2.4	19.5	164	6.0	79	8	292	0
1937–38	43.4	10.5	38.0	12.8	4.5	0.85	3.1	14.1	186	5.7	65	6	356	0
1938–39	47.8	11.4	39.3	13.2	5.3	0.95	4.6	11.4	201	6.3	75	7	357	0*
1939–40	43.2	11.9	36.2	8.7	4.2	0.8	2.3	16.1	159	11.0	63	6	350	0
1940–41	42.1	10.7	35.8	12.1	3.7	0.8	3.2	13.8	136	10.1	60	7	362	0
1941–42	46.2	9.9	37.7	13.0	4.6	0.95	2.9	14.3	153	7.5	65	7	358	0
1942–43	50.2	11.6	41.3	18.5	5.0	0.85	1.8	8.6	165	9.3	68	7	356	0
1943–44	53.3	12.8	45.8	24.8	5.1	0.9	3.2	8.4	192	6.9	68	6	358	0
1944–45	48.5	12.8	41.8	21.6	5.0	0.95	3.1	8.9	184	11.2	72	8	352	0
Average	46.5	11.3	39.2	14.7	4.6	0.85	3.0	12.7	171	8.3	68	7	Total 3141	0*

* One doubtful sample.

Period of Aeration. The period of aeration given in the tables is calculated on the total tank capacity in relation to the sewage flow. The tank capacity set aside for sludge reaeration is expressed on the same basis.

The average aeration period for the nine years is 6.62 hours to which must be added 0.88 hours (based on the sewage flow) for reaeration, giving an over-all capacity of 7.5 hours detention.

This result should be assessed in relation to the strength of the settled sewage treated, which had an average B.O.D. of 171 p.p.m., and to the fact that purification was consistently taken to the point of advanced nitrification.

Air Supply. In deciding on the volume of air to be supplied to the activated sludge plant, questions of efficiency and smooth running of the power plant have received appropriate consideration. For this reason, the quantity of air supplied to the plant has not always been precisely equal to the minimum necessary for obtaining nitrification at approximately the maximum rate. On some occasions the air supplied has somewhat exceeded, and on others has been rather less than the minimum required for this purpose.

The rate of air supply is varied only moderately and at infrequent intervals in accordance with the general trend of the pollution load in relation to the plant activity. Owing to the ample supply of air normally obtaining, there has been found no necessity to make daily adjustments based on the volume or strength of the sewage, or on hour to hour operating conditions such as the amount of dissolved oxygen present.

The figures of air consumed are inclusive of all air used in supply and outlet channels, return sludge channels, and miscellaneous requirements.

Air per Gallon of Sewage and Air per lb. of B.O.D. Removed. As is well known, the volume of air required to purify sewage by activated sludge depends largely upon the strength of the sewage and its preliminary treatment, the water depth of the aeration tanks, and whether the objective is limited to clarification of the sewage or extended to the production of effluents containing appreciable amounts of nitrate.

The sewage dealt with at Mogden as judged by American standards is of relatively high strength..

During the nine-year period, about 45 per cent of the B.O.D. and over 70 per cent of the suspended solids of the sewage treated in the aeration tanks were removed by preliminary sedimentation. The more difficult work of removal and oxidation of very fine suspended solids, colloidal matter and impurities in true solution remaining in the settled sewage, was effected in the aeration tanks with the use of an average air supply of rather less than 1 cu. ft. per U. S. gallon, or 717 * cu. ft. per lb. of B.O.D. removed, with the regular production of a well nitrified effluent.

* As explained in the comments on analytical results, owing to occasional anomalous B.O.D. results in respect to the activated sludge effluent, the average volumes of air given in Table III slightly exceed those actually required for the removal of 1 lb. B.O.D.

In assessing these results, the following considerations on the main factors mentioned above should be taken into account:

(a) The depth of tank, which at Mogden is 12 feet. The air for this depth is at a lower pressure than for the more common 15-foot depth of tank, and therefore the power required is correspondingly less in comparison with other plants than the air per lb. of B.O.D. would indicate. A better yardstick would be "h.p.-hours per lb. of B.O.D. removed" but this would inevitably introduce extraneous matters such as condition of diffusers, friction losses in supply mains, efficiency of blowers, and so on.

(b) The proportion of pollution load removed by preliminary sedimentation. If the B.O.D. load dealt with by the activated sludge process were increased by passing forward a proportion of heavier suspended matter, as is common practice with the shorter sedimentation periods in America, the air per lb. of B.O.D. removed would be considerably reduced.

(c) The production of nitrified effluents. The main objectives at Mogden have been previously stated as the maintenance when operating with strong sewage of aerial conditions as fresh as possible, the provision of ample safeguard against sludge bulking, and the production of an effluent of high quality at all times. These requirements can be amply satisfied by carrying the purification process to the nitrification stage.

Having regard to all these factors, and to the relatively short detention period required for nitrification under the aeration conditions adopted, the use of 700 cu. ft. of air per lb. of B.O.D. removed is regarded as very satisfactory.

It may be mentioned that during the nine-year period, the minimum value of nitrate content occurred during the 4 weeks, March 1–28, 1943, owing to low temperature and low air supply. During this period, when the average B.O.D. of the settled sewage was 190 p.p.m., the combined nitrite and nitrate content of the effluent was no more than 4.1 p.p.m. The air consumption during these four weeks of low nitrification was 0.91 cu. ft. per gal., and the average aeration period was 7.5 hours, a result which indicates that the treatment of the sewage at Mogden to a point no further than the stage of clarification would not result in any large reduction in air consumption or in tank capacity.

Return Sludge. The rate of sludge return is limited by the output of the pumps installed, which have a capacity of approximately 24 million U. S. g.p.d. On the 1936 dry weather sewage flow of 48 m.g.d., this capacity allowed a 50 per cent sludge return, but as the sewage flow increased, this percentage dropped accordingly. On the nine-year average flow of 72 m.g.d. it is only 33 per cent, and this may be reduced in wet weather to 13 per cent.

For Mogden conditions, experience has shown the value of a high rate of return sludge, particularly in times of maximum sewage flow in

wet weather. It is therefore probable that when opportunity permits, the capacity of the return sludge pumps will be increased to allow for a discharge equivalent to at least 25 per cent of the sewage flow through the aeration tanks in times of storm.

Mixed Liquor Suspended Solids. The average figures quoted in Table III were calculated from (a) records of the volumes of sludge obtained each day after one hour settlement of two average samples of mixed liquor; (b) results of daily determinations of the total solids in 100 ml. of each of the settled sludges, and (c) results of occasional determinations of the dissolved solids in the interstitial water of settled sludges.

The average volume of sludge in the mixed liquor, as measured after one hour settlement, during the period June to December, 1936, was 17 per cent. Subsequently the volume has been kept at about 15 per cent. This reduction was effected solely to avoid an undue accumulation of sludge in the final separating tanks during periods of very high flow in wet weather, and the possible discharge during such times of effluents containing an excess of suspended solids.

During the first yearly period, the weight of solid matter per 100 ml. of settled sludge was exceptionally high, notwithstanding the fact that the organic content of dry solids was 80 to 85 per cent. Subsequently, the weight became somewhat lower, although it was still sufficiently high to give ample satisfaction.

This lowering of the weight of solids (or "density" of the sludge) was parallel with several changes: (a) reduction in volume of air per sq. ft. of the aeration tank, (b) large increases in the discharges to the sewers of yeast waste and brewery effluent and (c) production of effluents of lower nitrate content.

There have been no noteworthy changes at Mogden in the density of the sludge corresponding to wet and dry weather, such as have been observed elsewhere (2) (3). This would appear to be due (a) to the high density and high degree of oxidation of the sludge and (b) to the efficient removal of grit and fine inorganic solids during the preliminary treatment of the sewage in grit chambers and sedimentation tanks.

No bulking of sludge has been observed at any time.

Sludge Index. The index figures quoted in Table III have been calculated, as for suspended solids in the mixed liquor, from determinations of the total solids contained in 100 ml. of settled sludge after one hour settlement, and of the dissolved solids in the interstitial water.

As there is no appreciable difference during the settlement of Mogden mixed liquor between the volume of sludge obtained after 30 minutes settlement and after one hour, the sludge index obtained in this way closely approximates the Mohlman index.

The index figures given in Table III, ranging from 42 to 85, with a nine-year average of 65, were obtained although the volatile content of the activated sludge, when dry, almost invariably exceeds 80 per cent.

Surplus Sludge. In nearly all cases, 25 to 50 per cent of clear super-

natant water can be removed from samples of surplus sludge after one hour settlement.

This sludge is generally passed to the primary sedimentation tank inlet for settlement with the raw sewage, but during the years 1938 to 1940, large volumes of mixed liquor, of which no accurate record is available, were discharged elsewhere for experimental purposes. In consequence, the usual surplus sludge data in respect of the two years covered by this period have been omitted.

Analytical Results

Sampling of Influent and Effluent. Samples of influent and effluent are taken at the end of every consecutive 2-hour period throughout the 24 hours of the day. For analysis, a daily average sample is made up in proportion to flow from each set of 12 samples.

Four-hour Oxygen Absorption from Acid Permanganate. Prior to the determination of the oxygen absorption of a sample, nitrite, if present, is destroyed by chemical means.

Five-day B.O.D. of Effluent and B.O.D. Removed. Occasionally anomalous results for the B.O.D. of the effluent are obtained owing to the oxidation of ammonia and/or nitrite occurring during the 5-day incubation period of the test. In consequence, the average B.O.D. figures for the effluent do not fully indicate the quality of the effluent produced. In such a case, this may be gauged more accurately by reference to the average figures for 4-hour oxygen absorption, albuminoid nitrogen, and suspended solids, and also by reference to the results obtained on incubation of samples of the effluent (in completely filled stoppered bottles) at 26° C. for a period of 6 days.

A question which appears to require further investigation is whether highly nitrified effluents containing a negligible amount of carbonaceous fermentible matter, and yielding anomalous 5-day B.O.D. results, are unsuitable or not for discharge to streams because of their possible effect on the content of oxygen in the stream and on fish life. Such abnormal B.O.D. results, however, certainly do not indicate correctly the amount of sewage polluting matter remaining in the effluents; nor does the difference between the B.O.D. of the influent and that of the effluent, in such cases, fully represent the amount of polluting matter removed by the activated sludge treatment.

Incubation Test (6 Days at 26° C.) for Effluents. To eliminate the personal factor as much as possible in making this test, each sample is tested for nitrite as well as for odor at the end of the incubation period. The presence of nitrite provides unmistakeable evidence that the liquid has not putrefied during the incubation period. The absence of nitrite in samples of the Mogden activated sludge effluent after incubation for 6 days at 26° C. is of extremely rare occurrence.

During one period of 24 hours, in the year ending March 31, 1939, owing to a heavy overload on the activated sludge plant, the effluent from one battery was unsatisfactory and putrescible, while the effluent from the other battery was non-putrefactive. The combined effluent

from these sections, after incubation for 6 days at 26° C., while not definitely putrescible was of doubtful quality and has been recorded so in Table IV.

Discharge of Effluent

The conditions for the discharge of the effluent into the Thames are unusually stringent for a plant of this size. The outfalls are located in a most picturesque stretch of the river flowing past the famous botanical gardens at Kew which are several miles above London city. Although the stream is tidal at this point, it is in a very clean condition and is used intensively for purposes of recreation including boating and fishing. No difficulties, however, have been encountered at any time on this account.

The experience with fish life in this part of the river may be of interest. The zone of pollution which exists through the industrial center of London effectively separates the sea fish of the estuary from the fresh water fish of the higher reaches. For many years prior to 1935, this zone of pollution had been extending upstream, with the result that by that date the fish had been driven above the point of the new effluent outfall and sellers of fishing tackle in that district had gone out of business. By the summer of 1936 when the new works had been operating a few months, the fish returned downstream and the river has been well stocked continuously since that time for a distance fully 5 miles below the point of outfall.

At various times during this period, the dilution ratio of river water to effluent has been very low. The average summer flow of fresh water discharged from the upper river at this point is 450 million U. S. g.p.d., while the drought flow may drop to 120 m.g.d. Under war conditions, however, the Metropolitan Water Board has been allowed to extract water from the upper river until the flow discharged into the tidal river over the last weir at Teddington has been reduced to under 50 m.g.d. for prolonged periods during summer weather. As there is practically no other source of fresh water discharging into the river above the outfall, the volume of effluent in the river water during such periods has reached a proportion of fully 50 per cent. Even so, no trouble has been experienced, which is not surprising when it is realized that many kinds of fish, including eels, roach, dace, and chub are known regularly to penetrate the effluent tunnels and to exist there quite happily.

Diffuser Plate Clogging

The air diffuser plates of the activated sludge plant are Norton stones, with a rating of approximately 45 to 50 cu. ft. per sq. ft. per min. under 2 in. of water pressure.

The plates are 8 in. by 8 in., and 6 in. by 8 in. in size, and are fixed into cast-iron trays in sets of four or six plates. Air-tight joints are obtained by rubber gaskets. Each tray is served by a G.I. pipe connecting with the supply main which is located in a trough formed in the top of the tank wall.

No appreciable increase in air pressure was noticed for the first three years of operation, after which sudden increases of one or two p.s.i. were observed. These were eventually found to occur with periods of maximum atmospheric humidity and the cause was traced to large accumulations of rust which had formed in the trays beneath the diffuser plates. This rust had partly originated from the G.I. down pipe and was partly due to the rusting of the cast-iron tray itself.

No clogging of the upper surface of the plates was found at any point except in the mixed liquor influent channel, and for a short distance at the inlet end of the aeration tanks; the plates in the reaeration unit, however, were not so free as those of the aeration units. A small deposit of soot was found on the underside of the plates, which indicated that the air filters on the blower intakes were not completely effective.

None of these things, however, had seriously affected the condition of the plates themselves. The main cause of the pressure rise was the blocking of the airways in the cast-iron trays.

Owing to the outbreak of war, it was possible to do very little work of reconditioning and the plant had been in operation for six years before the pressure for prolonged periods had risen 2.5 to 3 lbs. above normal and had reached the limit of 9.5 p.s.i. at which it was practicable to operate the blowers.

During the past three years, the whole of the diffusers have been dismantled and the cast-iron trays treated by sandblasting and metal spraying with zinc. Opportunity has been taken, at the same time, to burn the diffuser plates at a temperature of 800° to 900° C. in a gas heated furnace, installed at the Works for this purpose. In this way the original rating of the plates has been virtually restored. It is anticipated that the trouble will not arise again in such a short period as before.

Sludge Disposal

The whole of the sludge, comprising mixed raw and surplus activated sludges from the sedimentation tanks, together with sludge from the stormwater tanks, is dealt with in the digestion plant. This consists of twelve circular tanks, each 70 ft. diameter with a side water depth of 32 ft., the battery having a total capacity of 12 million U. S. gallons. Four tanks have fixed roofs and stirring mechanisms, while eight tanks are covered by floating gas holders of the spiral carriage type. From experience in operation, the gas holder tanks are preferred on the score of simplicity, fool-proof operation with elimination of explosion hazard, flexibility of control and availability of gas storage capacity without a separate holder installation.

The tanks are heated by coils supplied with hot water from the power station. Sufficient heat for this purpose has been available from the engine cooling water, even in the coldest weather, without making use of the heat of the exhaust gases. The temperature of the sludge is normally maintained at 85° F.

The average daily production of mixed sludges is about 480,000 U. S. g.p.d., at which volume the digestion period is about 25 days. After this period, the sludge is pumped seven miles to the disposal site at Perry Oaks where digestion is further continued in secondary and storage tanks of a total capacity of 19 million U. S. gallons before being dried on underdrained beds of gravel and ashes.

The mixed sludges are normally 95 to 96 per cent water, the solid matter having an average organic content of about 75 per cent, rising on occasion to nearly 80 per cent. A reduction of about 50 per cent of the organic matter is obtained in the primary stage at Mogden.

The digestion capacity on the present population works out at 1.33 cu. ft. per capita in the primary stage at Mogden and 2.13 cu. ft. per capita at Perry Oaks, or a total of 3.46 cu. ft. per capita. This is found none too large for dealing with sludge containing the whole of the surplus activated, in fact, it has been necessary to construct additional earth lagoons for storage purposes during the winter months when drying is at a standstill.

The drying area provided is 360,000 sq. yd. or 2.7 sq. ft. per capita. Here again, this is not too large for the type of sludge handled under English climatic conditions.

The whole of the dried sludge, amounting to about 60,000 cu. yd. per annum, is sold at a small charge for agricultural purposes. The present demand is very much greater than the supply.

The maximum yield of gas from the digestion plant at Mogden was obtained in the year 1939–40 when the twelve months' production reached 490 million cu. ft. or an average of 1,350,000 cu. ft. per day, equivalent to over 1.1 cu. ft. per capita. The yield has fallen somewhat during the war years due to fluctuations in population and to food rationing which has resulted in decreases of waste grease, etc., but output has usually been well in excess of 460 million cu. ft. per annum.

Of this total, the normal consumption of the power station is about 425 million cu. ft. while a further 20 million cu. ft. is used in heating the main buildings and for operating the department's vehicles. For the latter purpose, the gas is compressed to 3,000 p.s.i. and delivered into high pressure cylinders fixed to the chassis, and holding a sufficient volume to give a travelling distance of about 80 mi. for each charge.

The digestion plant has made a most valuable contribution to the conservation of national fuel resources, particularly in the emergency conditions of wartime. The saving of diesel and fuel oil per annum has exceeded 1,500,000 U. S. gallons which would otherwise have had to be imported at a cost of nearly £60,000. In regard to power requirements, the Works is entirely self-supporting and no alternative supply is available from outside sources. From the point of view of reliability, the installation is more completely trustworthy than the public supply and no failure of any kind has been recorded during its ten years of operation.

The crude gas consists of about 69 per cent methane, 30 per cent carbon dioxide and traces of other gases. In the power plant it is used

without any form of preliminary treatment but before compressing for use on vehicles, the carbon dioxide is reduced to about 5 per cent by washing at 20 p.s.i.

The main power plant consists of ten engines each of 650 b.h.p. on oil fuel, or 550 b.h.p. on gas. At the commencement of operation in 1935, the plant was started up on fuel oil; the engines were converted for running on methane as the gas became available. Two engines are permanently reserved for running on oil if a shortage of gas should occur on any particular day. In practice over 97 per cent of the total annual power output is obtained from sludge gas.

Several years ago one of the standby oil engines was converted for operation on the dual fuel principle by which part of the diesel oil is replaced by gas in any desired proportion down to a minimum of about 10 per cent of oil, by the simple movement of a control lever. The power and efficiency of the dual engine when running on 90 per cent gas is not lower than when operating fully on oil as a diesel engine. The exhaust temperatures are considerably lower than for the normal gas engine and experience indicates reduced maintenance.

Of the ten engines, six are employed in driving turbo compressors, each having a maximum capacity of 15,000 cu. ft. of free air per min., and four are coupled to D.C. generators, each of 375 kw. capacity at 460 volts.

Operating Personnel and Costs

The wartime conditions of operation, which still prevail, have been so abnormal that information on personnel and costs relating to a recent period would be completely unreliable and misleading. The following statistics of pre-war conditions of 1939 have therefore been selected as being more representative.

The number of personnel employed at Mogden in 1939 was about 160, at Perry Oaks 40, and on the main sewers 25, making a total of about 225. This covered all supervisory grades of works management but not administrative or office staff comprising engineering, chemical or clerical personnel.

The Mogden figure included not only shift operators, day operators and general maintenance men on plant, gardening, transport, stores and miscellaneous, but also:

(a) Mechanical and electrical maintenance of the sewage pumping station and power station, which are additional to the usual pumping and other stations, machinery, metering instruments and equipment of a normal works, and

(b) Building trades and miscellaneous maintenance, including carpenters, painters, concretors and general handymen engaged on works buildings and plant, painting of outside machinery, penstocks, etc., maintenance of fifty workmens' houses, and miscellaneous alterations and development work.

The Perry Oaks staff was usually increased to nearly 50 during the sludge lifting season of the summer and decreased to a winter level of about 30. It may be of interest to note that the whole of the dried sludge from a population of about 1,200,000 was hand-lifted by an average of 12 men working for a normal period of six months in each year, that is by about 6 man-years per annum. The average output, working on a bonus system, is 40 cu. yd. per man per 8½-hour day. These figures are, of course, exclusive of laying and moving temporary rail tracks, haulage and tipping, etc.

The capital cost of the works of Mogden and Perry Oaks has already been given as approximately £2,000,000. This includes the main sewage pumping station and also reserve plant not yet brought into use. Allowing for these items, the cost of the purification and sludge disposal plant at present in operation, inclusive of the power station, was about £1,700,000.

The annual pre-war cost of operation was approximately £60,000 including salaries, wages, materials and services, to which must be added £10,500 for the sewage pumping station and £6,250 for main sewers, a total of £76,750. This again does not cover administrative or office staff, or other expenditures such as rates and taxes, which are heavy items under present British conditions, but which may have no counterpart in other countries.

It is too early to forecast what postwar costs are likely to be. At the present time, the hourly wage rates have risen by about 35 to 40 per cent over the 1939 levels but total costs have not been affected in this way because of the drastic cuts in operating manpower.

It may be difficult to compare British costs with American conditions, more particularly as the present rate of exchange favors the United States and Canadian dollars, this having the effect of making British costs appear cheap in America and United States costs very expensive in Britain. As the manhour is the only common basis, it may be mentioned that the present wage levels are about 38 U. S. cents per hour for unskilled labor, rising to about 45 or 48 cents for the skilled worker in engineering or building trades.

The main source of income is derived from a flat rate per £ of rateable value of all property within the drainage district. The over-all cost of the undertaking works out at about 7 shillings per capita per annum, inclusive of all loan charges, operating and miscellaneous expenses, but exclusive of rates and taxes paid back to local and Government authorities under British taxation procedure, on the value of the disposal works and property belonging to the undertaking.

With regard to the treatment of trade waste, it has been the policy since the responsibility for sewage disposal was transferred from the Local Authorities in 1936, to make a charge for all new discharges of factory effluent on the basis of the actual cost of purification. This is assessed in as fair a manner as possible on a non-profit basis and the industry is given the benefit of a lower charge in respect to any reduction he may be able to make in the pollution load discharged.

In view of the increasing interest which has recently been shown in this subject in America, it may be mentioned that this system of assessment has been in operation in West Middlesex for nine years with very satisfactory results. The costs of disposal are subdivided into the three main items:

1. Preliminary treatment, including pumping, screening, grit removal, sedimentation, etc., the cost of which is all more or less proportional to the volume of flow.
2. Biological purification by activated sludge, the cost of which is proportional not only to the volume, but also to the strength of the settled waste.
3. Sludge disposal, which is taken to depend on the suspended matter present in the waste.

A formula has been evolved incorporating these three items and giving a charge per thousand gallons for any given trade effluent from the results of analyses of an appropriate number of samples. In effect the charge is made on the basis of a fixed charge per thousand gallons, plus so much per ton of pollution load remaining after sedimentation, plus so much per ton of suspended solids.

In this manner, it is in the interest of the industry to reduce the load of waste discharged to the sewers. It very frequently happens that it is found possible to do this and at the same time to achieve a reduction in factory costs by the recovery of by-products, by the re-use of liquids, or in some other way.

War Record

By way of conclusion, it may be of interest to record that in common with very many sewage plants in Britain, Mogden had its share of war incidents and, like them, proved how relatively well this kind of public service is able to stand up to such conditions.

For four years from 1940 to 1944, German occupied territory remained only 90 miles distant, or not more than 20 minutes flying time. The plant was one of the best known landmarks in the London district; it was in the area over which the Battle of Britain was fought and remained well inside the range of flying bombs and rockets to the last week before VE day.

At various times, the Works received samples of high explosive, phosphorus, incendiary and explosive incendiary bombs, parachute flares, and so on. Two final tanks were wrecked and others damaged, sundry sludge mains shattered, and two gasholders set on fire; 20 explosive incendiaries burst inside the power station all around and on top of the engines, knocking holes through the main switchboards, engine frames and compressor casings; desludging machines were fractured; showers of anti-aircraft shell splinters were a nightly occurrence for prolonged periods, breaking diffuser plates in aeration tanks, damaging roofs and puncturing air distribution mains; the digestion tanks

are operating today with six unrecovered explosive incendiaries buried in the depths of the sludge. And so on.

Yet never did the plant fail to produce a first class effluent from the whole of the sewage received, nor was any process interrupted for the shortest length of time. The power supply, both of electricity and compressed air, never failed, nor was any power unit shut down involuntarily at any time. Not a single man was injured in any way.

In many cases, a major shut-down was missed by a matter of inches but it never happened.

The main sewerage system was not so fortunate. Several items of serious damage occurred but the outstanding incident was that of a single bomb, estimated of at least 2,000 lbs. weight, which completely wrecked a 10-foot sewer over a length of 130 feet. The sewer had been constructed in tunnel at a depth of about 40 feet below the surface but the bomb, which fell just clear of the tunnel lining, penetrated the ground to a depth of about 50 feet and destroyed the sewer from below. The repair work was extremely difficult and carried out under the worst wartime conditions, which resulted in the sewage from 400,000 people failing to reach the purification plant for 6 months.

Administration

The West Middlesex project was carried out by the Middlesex County Council, to which body was transferred complete responsibility for main drainage and sewage purification within the Main Drainage District. The Local Authorities continue to be responsible for local tributary sewers which discharge into the main sewers at agreed points.

The undertaking is organized for administration purposes as a department of the County Engineer, Major W. H. Morgan, C.B.E., D.S.O., M.Inst.C.E.

Bibliography

1. William T. Lockett, "A Contribution to the Literature Relating to the Activated Sludge Process," *Institute of Sewage Purification J.*, **II**, 101 (1937).
2. Ardern and Lockett, "Activated Sludge Process: Withington Works (Manchester)," *J. Society of Chemical Industry*, **XLII**, 21, 225T–230T (1923).
3. American Public Health Association, "Activated Sludge Sewage Treatment Works," *Sewage Works J.*, **14**, 1, 3 (1942).

COMPARISON OF ANALYSES OF COMPOSITE SAMPLES COLLECTED OVER EIGHT, SIXTEEN AND TWENTY-FOUR HOURS

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The purpose of this paper is to set forth the relationship between various sampling periods for sampling of raw sewage and effluents in military camps. There is need for a method of comparing results of sampling when partial sampling periods are used, such as an 8-hour period against a 24-hour period or a 16-hour period against a 24-hour period. The following data represent the results at one large Army training camp:

Procedure Used in Conducting Test

The test was conducted for a period of 28 days, from February 1, 1945, to February 28, 1945, inclusive, at the sewage treatment plant at Fort Knox, Kentucky. The plant consists of primary treatment, secondary treatment by high rate filters and chlorination of the plant effluent.

Samples were collected by the regular plant operators once an hour on the hour. The samples were taken from two points for the test; first—raw sewage—in the influent channel ahead of the primary clarifier; second—plant effluent—in the effluent channel after chlorination. The samples were refrigerated until used. The samples were composited proportionally to the rate of flow in the following manner: Three bottles of two-liter capacity for each sampling point were marked as follows:

Bottle No.	For Sampling Period	Composite Sample
1	0800 to 1600	8 hours
2	0800 to 2400	16 hours
3	0800 to 0800	24 hours

From 0800 to 1600, the operator placed equal portions of the weighed sample into bottles No. 1, No. 2 and No. 3.

From 1600 to 2400, the operator placed equal portions of the weighed sample, in proportion to the rate of flow at the time the sample was taken, into bottles No. 2 and No. 3.

From 2400 to 0800, the operator placed a portion of the weighed sample into bottle No. 3.

The 5-day B.O.D. and suspended solids were run on the three composited samples for the raw sewage samples and the plant effluent samples during the morning immediately after the last sampling period of the 24-hour composite sample.

The procedure used for the analytical work was in accordance with *Standard Methods for the Examination of Water and Sewage*, Eighth Edition.

The 5-day B.O.D. determinations were made as follows:

(1) Two dilutions were made for the composited sample.

(2) Three bottles were incubated for each dilution.

(3) One blank was incubated for each dilution.

(4) Dilutions were made with a volumetric pipette into a glass stoppered volumetric flask. Then the flask was shaken by inverting twenty times before withdrawal was made by siphoning into the B.O.D. bottles.

(5) The B.O.D. bottles were prepared for titration exactly five days or 120 hours after incubation. The distilled water used in the B.O.D. test was not aerated because of a high initial oxygen content but was buffered with bicarbonate. The distilled water was seeded before use. The suspended solids determinations were made in triplicate on each composited sample. Fifty ml. of the sample were used for each gooch crucible.

Results of Test

The average results for the twenty-eight days are shown in Table I.

Table I.—*Average Results of 28-Day Test*

Length of Sample Period (Hrs.)	Time of Period	Average Rate of Flow (M.g.d.)	Raw Sewage		Plant Effluent	
			5-Day B.O.D. (P.p.m.)	S.S. (P.p.m.)	5-Day B.O.D. (P.p.m.)	S.S. (P.p.m.)
8	0800 to 1600	4.714	378	376	30.6	42
16	0800 to 2400	4.814	335	337	37.9	44
24	0800 to 0800	4.031	268	286	35.0	46

The differences between the three sampling periods of raw sewage are shown in Table II, using the 24-hour period as the base of comparison.

Table II.—*Comparison of Raw Sewage Samples*

Sampling Period	Difference in P.p.m.		Percentage Difference	
	B.O.D.	S.S.	B.O.D.	S.S.
8 hrs. greater than 24 hrs.* by.....	109	90	+41	+31
16 hrs. greater than 24 hrs.* by.....	43	39	+16	+14
8 hrs. greater than 16 hrs.** by.....	66	51	+20	+15

* Using 24-hour composite sample period as base.

** Using 16-hour composite sample period as base.

The differences between the three sampling periods of the plant effluent are shown in Table III, using the 24-hour period as a base.

TABLE III.—*Comparison of Plant Effluent Samples*

Sampling Period	Difference in P.p.m.		Percentage Difference	
	B.O.D.	S.S.	B.O.D.	S.S.
8-hr. to 24-hr.	−4.4	−4	−12.6	−8.7
16-hr. to 24-hr.	+2.9	−2	+ 8.3	−4.3
8-hr. to 16-hr.	−7.3	−2	−19.3	−4.5

A follow through the detention times shows that usually the plant effluent during the 8-hour sampling period is the flow that has entered the plant during the early morning hours when the strength of the raw sewage is at a minimum; while plant effluent during the last eight hours of the 24-hour sampling period, that is from midnight to 0800, is the flow which entered the plant during the early hours of the evening and represented the highest strength raw sewage.

In using the results of the sampling periods to show percentages of removal for the twenty-eight days, the 8-hour composite sample shows 4.9 per cent higher reduction in B.O.D. and 4.9 per cent higher reduction in suspended solids than the 24-hour sampling period, as set forth in Table IV.

TABLE IV.—*Comparison of Removals*

Sampling Period	Percentage Reduction B.O.D.	S.S.
8-hr.	91.9	88.8
16-hr.	88.7	87.0
24-hr.	87.0	83.9

CONCLUSION

A true comparison of operation results is not given when varying lengths of sampling periods are used. Results of 8-hour composite samples of raw sewage for army training camps are higher than 24-hour composite samples by approximately 41 per cent in B.O.D. and 31 per cent in suspended solids.

Note: Individual results of all analyses are on file with the Sanitary Section of Repairs and Utilities Division, Headquarters, Fifth Service Command, Fort Hayes, Columbus 18, Ohio. The work was accomplished as the result of discussions at the Fifth Service Command Sewage Treatment Conference held in September, 1944.

Research

THE USE OF DIGESTED SLUDGE AND DIGESTER OVERFLOW TO CONTROL BULKING ACTIVATED SLUDGE *

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A method of control of the sludge index of activated sludge has been developed at Peoria, Illinois, by the application of digested sludge to the activated sludge system. The operation of the activated sludge plant has been continuously complicated by the presence of bulking activated sludge which resulted in the periodic production of inferior effluent and in digested sludge of low solids concentration. Efforts to control the bulking by the use of reaeration of return sludge, preaeration of preliminary tank effluent, frequent exacting volumetric adjustments of mixed liquor and return sludge ratios as necessitated by changing sludge indices, reduction of load during bulking periods, and the use of toxic agents such as copper sulfate solutions and chlorine met with indifferent success. Occasionally these corrective measures were satisfactory; frequently they were not. Not until the use of digested sludge was employed to remedy the situation has the sludge index kept within close limits. Since the process has been best adapted to the Peoria requirements the monthly average plant efficiency has been in the order of 95 per cent removal of B.O.D. and suspended solids, and at no time has sludge been lost over the final settling tank effluent weirs.

Since either or both bottom digested sludge or overflow digested sludge may be used, the process is a complete solution to the so-called "supernatant liquor problem."

Nature of Problem

The problem at Peoria is the treatment of the sewage of about 115,000 population together with industrial wastes of about equal population equivalent in an activated sludge plant employing preliminary sedimentation and separate sludge digestion.

The industrial wastes consist largely of wastes from breweries, packing houses and paper mills. The wastes are high in dissolved carbohydrates, which result in monthly average reducing sugar concentrations in the plant influent of about 30 p.p.m. with daily averages as high as 100 p.p.m.

* A special contribution originally prepared for presentation in the technical program of the Eighteenth Annual Meeting and Sixth Annual Convention of the Federation, since postponed.

Figure 1 indicates the nature of the plant load, as analyzed by population equivalent averages, for the days of the week for a month of dry weather flow. The variation in load is, of course, largely due to the variance of industrial operation.

With this type of sewage three problems arise in the operation of the activated sludge process:

First, and of greatest importance, is the practically continuous "bulking" of the activated sludge.

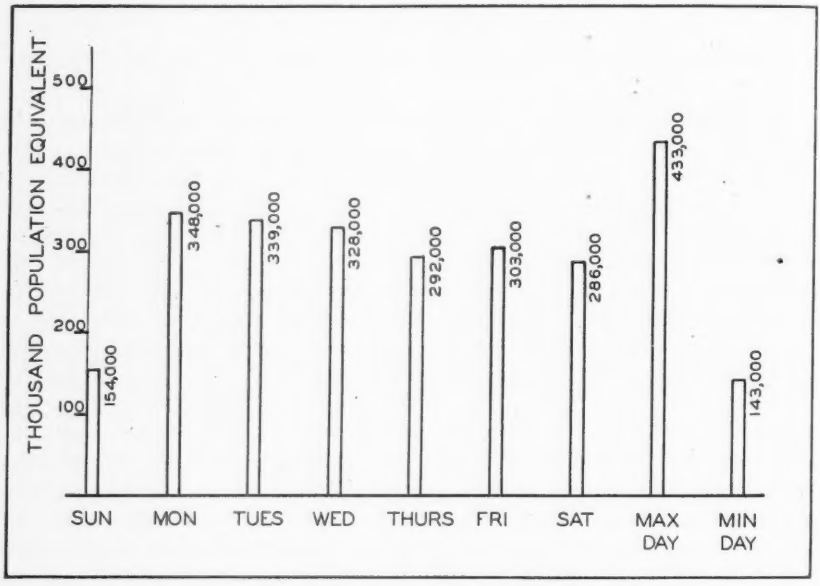

FIGURE 1.—Variation of raw sewage population equivalent by average of days of week for month of dry weather flow.

Second, is the loss of clarifying properties of the activated sludge due to shock loads of as high as 400,000 population equivalent as a daily average on a plant designed to treat about half this load, which loss persists for as long as 10 days following the shock load.

Third, and of least importance, is the rising of activated sludge in the final settling tanks, possibly due to denitrification of nitrate nitrogen and consequent gas-lifting of the sludge from the bottom of the tank. This effect is observed largely on week end periods and on holidays when industrial activity is low.

PROPERTIES OF ACTIVATED SLUDGE

Studies of the properties of activated sludge over many years of plant operating data disclose several salient facts. Invariably, regardless of the method of plant operation, more activated sludge is produced than can be accounted for by the suspended solids removal from the set-

tled sewage. Accompanying this increase in suspended solids is the conversion of some of the ammonia nitrogen to organic nitrogen. The increase in suspended solids probably results from the removal of soluble and colloidal materials and their conversion to sludge solids.

The effect of this conversion of dissolved and colloidal solids to suspended solids is to produce a sludge of high organic matter content and of poor settling characteristic and high sludge index (Mohlman (1)). This is probably due to the conversion of part of the dissolved and colloidal organic material to bacteria and bacterial exudate, which materials are of very high organic matter content (probably over 95 per cent) and have exceedingly poor settling characteristics.

The rate of change of sludge index varies inversely as the total amount of activated sludge in the system. This is obvious if one considers the mathematics of the activated sludge system. The greater the mass of sludge in the system, the more buffer it offers to changes. If the system tends to produce a sludge of high sludge index due to the conversion of dissolved and colloidal materials to sludge of poor settling characteristics, the more sludge available in the system the lower will be the rate of change brought about by this effect.

The sludge index is usually reduced during periods of stormflow, however, this effect is not observed during moderate rains which do not result in considerable by-passing of sewage and flushing of the sewers. This effect is probably brought about by the washing of materials of high density and low organic matter content into the activated sludge and also by the reduction in dissolved and colloidal materials in the sewage which in turn reduces the amount of poor settling activated sludge produced from them.

The loss of clarifying ability of the activated sludge is brought about by either a very high load on the plant or by a very sharp reduction in sludge index. The effect of a shock load is first observed in a depletion of dissolved oxygen in the aeration tanks and this is usually followed by a loss in clarity of the plant effluent. The clarifying ability is not restored when the dissolved oxygen level in the aeration tank is reestablished, and it usually takes many days before good clarification can be regained. Loss of clarification is also brought about by a sharp reduction in sludge index, *e.g.*, from 300 to 150 in 12 hours. This can be corrected readily by increasing the suspended solids in the aeration tanks.

Floating sludge is produced when the plant load is sharply reduced. This can be largely controlled by reducing the dissolved oxygen in the aeration tanks.

The use of chlorine at 5 p.p.m. in the return sludge is not always effective in reducing the sludge index.

Ruchhoft, et al. (2), in a classic study of oxidation, adsorption and synthesis relations in the activated sludge process pointed out the need for balance between the carbonaceous material removed by oxidation and by net adsorption and synthesis in order to keep activated sludge in continuously good condition.

This work affords the key to the bulking troubles in the activated sludge process. Among other findings it points out that during the early period of aeration, adsorption and synthesis (conversion of dispersed, colloidal and dissolved material to sludge solids) is the predominant action in the activated sludge process, while oxidation takes place in the later stages of the aeration period. It also concludes that biochemical oxidation is a factor of major importance to the success of the process.

Thus it would appear from Ruchhoft's conclusions that if a sewage was of such character that oxidation was a minor factor in the purification process, the efficiency of treatment would be ultimately reduced.

Heukelekian and Ingols (3), in their studies of activated sludge bulking, concluded that insufficient dissolved oxygen and excessive loading can cause bulking and that the presence of nitrate nitrogen prevents bulking.

That excessive loads and insufficient dissolved oxygen in the aeration liquor produce bulking has been repeatedly demonstrated in both plant and laboratory. This again seems to agree with Ruchhoft's conclusion regarding oxidation being necessary to the success of the process, since under these conditions it is doubtful whether the oxidation stage of the reaction is attained.

In this paper (3) the desirability of having nitrate nitrogen present in the aeration tanks as a preventative for bulking has been repeatedly stressed. In the studies cited, a reduction in sludge index occurred in those samples in which nitrate nitrogen was added, while in the control determination the sludge index increased sharply. The authors recommend the use of nitrate as a control measure where its addition is economically possible.

Lackey and Wattie (4) in their studies of the biology of *sphaerotilus natans* in relation to bulking activated sludge point out that the organism may be the effect of bulking rather than the cause and indicate that the control of the growth of the organism by the use of toxic agents such as chlorine is effective but expensive.

Ruchhoft and Kachmar (5) state that *sphaerotilus natans* is not the primary cause of bulking but that bulking is brought about by a disturbance in the balance of sludge, food and oxygen.

Sawyer (6) has pointed out the importance of having a proper relationship between the ammonia nitrogen and carbohydrate content of the sewage to be treated. If excessive carbohydrate is present the activated sludge produced increases greatly in quantity and also in sludge index. In addition, sewages with low ratios of B.O.D. to ammonia nitrogen produce activated sludges with great ability for oxidation while sewages with high ratios of B.O.D. to ammonia nitrogen produce activated sludges with very poor properties for oxidation.

Ingols and Heukelekian (7, 8) have stressed the importance of having the proper relationship between carbon and nitrogen and conclude that while food, sludge and dissolved oxygen are the important factors

in determining the characteristics of an activated sludge, the deficiency of dissolved oxygen is more conducive to bulking than the other factors.

Requirements to Solution of Problem

There is general agreement among the students of the activated sludge process that the major factors of control of the process efficacy are sludge, food, air and proper means for applying these factors. From a practical standpoint we have little control of the sewage characteristics entering the plant and due to cost and physical limitations the maximum quantity of air available at the plant is relatively fixed.

The requirements for a solution to our problem appear to be as follows:

1. Increase the activated sludge in the system to afford a buffer against rapid rate of change of sludge index.
2. Increase the settleability of the activated sludge by introducing a material of greater density than the normal activated sludge produced.
3. Provide in the process a means of increasing the oxidative action of the sludge to more nearly balance the existing condition of synthesis of solids brought about by excessive quantities of carbohydrates present in the sewage.
4. Provide in the process additional ammonia nitrogen to balance the excessive quantities of carbohydrates present in the sewage.
5. Provide nitrate nitrogen concentrations sufficient to prevent bulking.
6. Provide a means of rapidly restoring clarifying properties of the activated sludge following "shock loads" in the plant influent.
7. Provide a means of controlling rising sludge.
8. Discontinue attempts to control sludge index by reducing load, and by the use of toxic substances in order to reduce the amount of *sphaerotilus natans* present in sludge.

The Solution to the Problem

While working with various controls and materials for solving our problem it was found that digested sludge could be readily converted to activated sludge by proper seeding and aeration. It was immediately apparent that by properly applying this material to the process that many of the requirements for a solution to our problem could be met.

It was found that when digested sludge is mixed with activated sludge in the proper proportions and aerated, the mixture after aeration becomes an activated sludge which has a sludge index that is approximately the weighted average of the sludge indices of the two sludges prior to mixing and aeration.

In addition, the ammonia in the digested sludge is converted to nitrate and nitrite nitrogen if the aeration period is sufficiently long and, also, this oxidation can be accomplished in concentrations in the order of 10,000 p.p.m. with reasonable requirements of air.

Figure 2 and Table 1 indicate the rate of change of suspended solids, sludge index, ammonia and nitrate plus nitrite nitrogen with a batch addition of digested sludge to activated sludge in an aeration tank. These are plant scale data and are typical of other such data obtained. Digested sludge was added to the sludge treatment aeration tank for a period of five hours. The sludge index of the activated sludge in this tank was reduced from 130 to 104 and the suspended solids were increased from 5,550 p.p.m. to 8,550 p.p.m. The suspended solids then

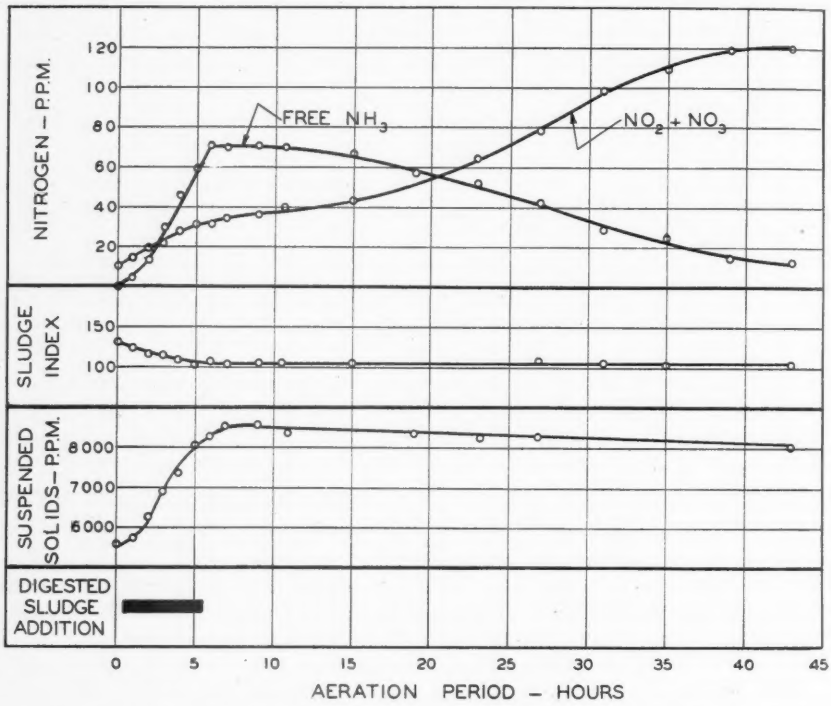

FIGURE 2.—Effect of adding digested sludge to activated sludge and aerating the mixture.

decreased slowly until after 32 hours a value of 8,100 p.p.m. was reached. The ammonia increased from 0 p.p.m. to 70 p.p.m. and was oxidized to nitrate and nitrite until after 32 hours it had fallen to 8 p.p.m. During this time the nitrate rose from 11 p.p.m. to 120 p.p.m. It appears that more nitrate plus nitrite nitrogen was formed than could be accounted for by the ammonia added. This effect was observed a number of times in the batch operations of the sludge treatment aeration tank and is considered to be caused by the decomposition of the activated sludge organic nitrogen to ammonia in one part of the tank and its subsequent oxidation to nitrate nitrogen. Where digested sludge is added continuously in moderate quantities and the aeration period is shorter, this effect is not observed.

TABLE 1.—*Effect of Adding Digested Sludge to Activated Sludge and Aerating the Mixture*

Period of Addition 5 Hours
Period of Aeration 47 Hours

Hours Aeration	Susp. Solids		Sludge Index (Mohlman)	Nitrogen (P.p.m.)	
	Total (P.p.m.)	Volatile Per Cent Dry Basis		Free NH_3	$NO_2 + NO_3$
0	5590	76.5	131	0	11
1	5690	75.7	122	4	15
2	6240	75.2	115	15	19
3	6900	73.8	117	30	22
4	7340	73.4	110	46	28
5	8050	73.7	105	56	31
6	8250	73.0	109	71	31
7	8550	71.8	105	70	34
9	8540	71.8	105	66	36
11	8380	71.3	107	69	39
15	—	—	—	67	43
19	8350	71.1	105	57	56
23	8230	70.6	108	52	64
27	8280	70.6	110	42	79
31	8270	70.6	105	29	98
35	—	—	—	25	109
39	—	—	—	15	119
43	8080	71.0	104	14	120

In order to introduce the digested sludge into the activated sludge system without adding load to the aeration tanks, the digested sludge is first converted to activated sludge in a sludge treatment aeration tank, after which it is interchanged with the activated sludge in the normal activated sludge portion of the plant. This is accomplished by

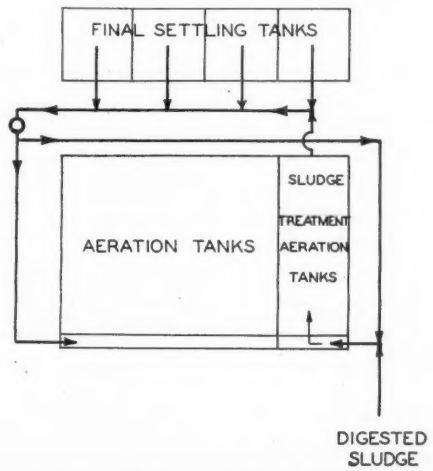

FIGURE 3.—Flow diagram of sludges during interchange.

TABLE 2.—*Effect of Interchange on Sludge in Sludge Treatment Aeration Tanks*

Interchange Period (Hours)	Susp. Solids		Sludge Index (Mohlman)	Nitrogen (P.p.m.)	
	Total (P.p.m.)	Volatile Per Cent Dry Basis		Free NH_3	$NO_2 + NO_3$
0	8080	71.0	104	14	120
1	7620	72.5	110	10	112
2	7260	73.2	119	9	99
3	7060	74.6	128	8	84

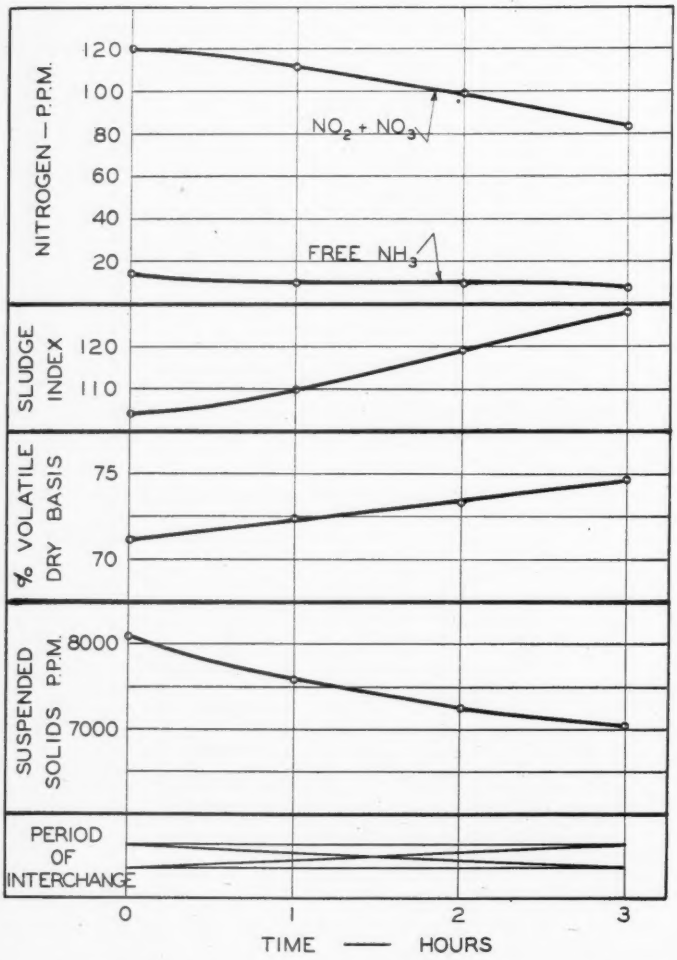

FIGURE 4.—Effects of high rate interchange on sludge in sludge treatment aeration tanks.

withdrawing part of the return sludge from the final settling tanks and adding it to the sludge treatment tank and adding the sludge treatment tank overflow to the normal return sludge. Figure 3 indicates a flow diagram for this interchange.

Table 2 and Figure 4 indicate the change in sludge index, suspended solids, ammonia and nitrate plus nitrite nitrogen during the interchange. Before the interchange was started the sludge index in the aeration tanks was 185 and the sludge index in the sludge treatment tank was 104. At the end of the interchange the sludge index of the activated sludge in the aeration tanks was reduced to 142 and the sludge

TABLE 3.—*Effect of Interchange on Alternate Days on Sludges in the Aeration Tanks and the Sludge Treatment Aeration Tanks*

Day	Aeration Tanks			Sludge Treatment Aeration Tanks					
	Susp. Solids		Sludge Index	Susp. Solids		Sludge Index	Nitrogen (P.p.m.)		Alkalinity (P.p.m.)
	Total (P.p.m.)	Volatile (Per Cent)		Total (P.p.m.)	Volatile (Per Cent)		Free NH_3	$NO_2 + NO_3$	
1	2310	78.1	153	5720	74.6	152	13	50	192
2	1920	80.9	151	6790	73.3	112	15	87	108
3	2110	78.9	146	5370	75.5	128	11	48	220
4	1890	83.3	161	6750	73.7	112	22	80	148
5	1810	80.6	131	4970	75.9	136	24	29	292
6	1800	78.9	128	6110	72.9	124	15	59	120
7	1880	81.3	132	5410	75.9	124	10	34	192
8	1540	80.1	130	6620	73.1	96	18	78	144
9	1920	80.2	123	5240	74.5	108	11	59	188
10	1920	81.3	156	6230	73.4	96	17	80	112
11	2160	78.9	134	5170	75.1	124	8	45	212
12	1820	81.8	177	6270	73.4	96	17	77	120
13	2050	80.4	137	5450	74.7	112	17	56	192

Note: Digested sludge is added continuously to the sludge treatment aeration tanks.

index of the sludge treatment tank activated sludge was increased to 128. In addition, the nitrate plus nitrite nitrogen in the sludge treatment aeration tank sludge decreased from 120 p.p.m. to 70 p.p.m. and this nitrogen was added to the aeration tanks. The oxidized nitrogen provides available oxygen in the influent to the aeration tanks where the demand for oxygen is high and augments the supply of dissolved oxygen provided by normal aeration. As stated previously, Ingols and Heukelekian have indicated the desirability of the presence of nitrate nitrogen to inhibit the growth of *sphaerotilus natans*.

In addition to providing a means of adding the digested sludge to the activated sludge system without imposing additional load on the aeration tanks, the sludge treatment tank provides a means of converting the ammonia nitrogen to nitrate plus nitrite nitrogen, and affords a change in environment for the activated sludge from one of predominantly adsorption and synthesis in the aeration tanks to one of oxidation in the sludge treatment tanks.

It can be seen that if the procedure of adding digested sludge and activated sludge to the sludge treatment tanks and aerating the mixture for a period sufficient to convert the digested sludge to activated sludge of low sludge index be followed by an interchange between the activated sludge in the aeration tanks and the activated sludge in the sludge treatment tanks, and the cycle repeated, a process is established whereby the

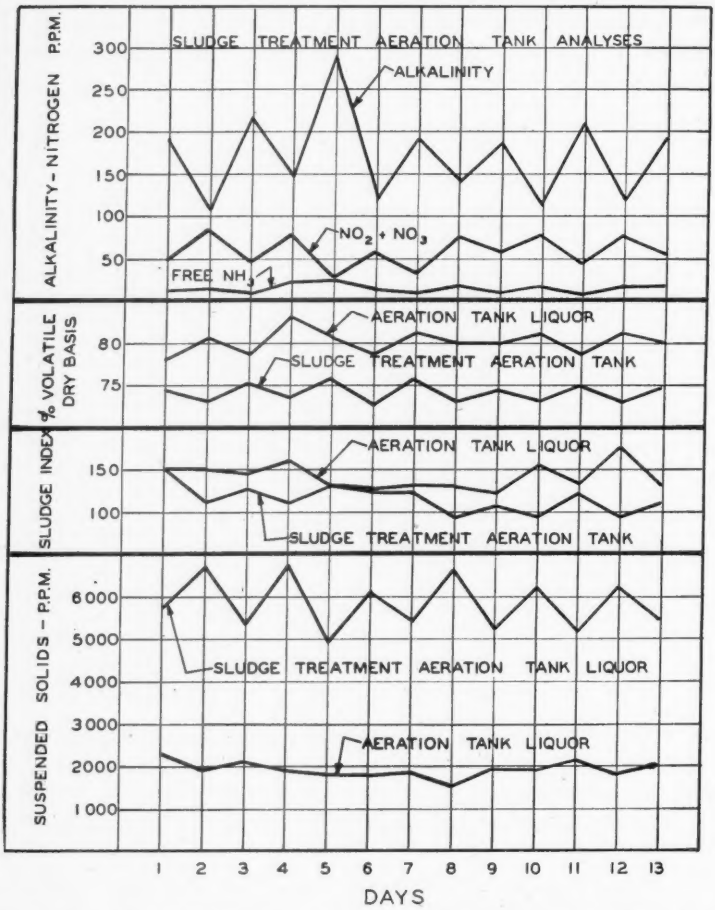

FIGURE 5.—Effect of low rate interchange on alternate days on sludges in aeration tanks and sludge treatment aeration tanks with continuous addition of digested sludge.

normal activated sludge will increase in sludge index between interchange periods and be reduced in sludge index during the interchange period.

Table 3 and Figure 5 indicate the conditions in both the aeration tanks and sludge treatment aeration tanks during an operation in which digested sludge is being added to the sludge treatment tank continuously. The sludges in the aeration tanks and sludge treatment

tanks are being interchanged at a relatively low rate for a 24-hour period beginning on the even day. At the end of the interchange period the sludge in one bay of the sludge treatment tank is being circulated from effluent end to influent end, thus affording dilution of the incoming digested sludge. During the circulating period (24 hrs.) the sludge treatment tank overflows at the rate of addition of digested sludge into the return sludge system.

The analyses presented are those of composite samples in both aeration tanks and sludge treatment aeration tanks taken at the beginning and end of the interchange. The data indicate a number of noteworthy facts:

1. That while the suspended solids in the sludge treatment aeration tanks increase materially during the period between interchanges the level of solids in the aeration tanks do not fluctuate more than in the normal process and are largely controlled by the normal wasting of activated sludge.
2. That the tendency to decrease sludge index and volatile matter in the aeration tank activated sludge is indicated during the interchange period and that during days of dry weather flow and no interchange the tendency is to increase in sludge index and volatile matter.
3. That the nitrate content in the sludge treatment tank can be maintained at a continuously high level and that during interchange periods the nitrate content in the sludge treatment tank is reduced and the amount lost is introduced into the aeration tanks.
4. That the oxidation of ammonia to nitrate is accompanied by a reduction in alkalinity due to the formation of nitric acid.

By the use of this process the suspended solids in the activated sludge system are considerably higher than are normally present in the conventional method. If in an activated sludge plant employing 6.7 hrs. aeration period and 1,000 p.p.m. aeration liquor with a sludge index of 200, the procedure here described is used, the sludge index may be reduced to 100 and the period in the aeration tanks be reduced to 5.0 hrs. The aeration tank solids may be maintained at 2,000 p.p.m. and the solids concentration in the sludge treatment tanks may be 8,000 p.p.m. The capacity of the sludge treatment tanks would be one-quarter of the total aeration tank capacity. Thus there is provided three and one-half times the activated sludge solids in this procedure that is provided by the conventional process.

It has been suggested that so great an increase in suspended activated sludge solids would greatly increase the air requirements of the system. The Peoria experience, however, indicates that no more air is required with about three and one-half times the solids in the system than was normally used and the net effect is the production of a better effluent than was formerly produced by the conventional process. The use of no more air is possibly due to three factors. First, the more efficient use of air in the sludge treatment aeration tank due to the con-

version of ammonia nitrogen to nitrate and nitrite nitrogen; second, the somewhat lower rate of oxygen utilization by the activated sludge; and third, the lack of fear on the part of the operator to operate at lower dissolved oxygen levels in the aeration tanks due to freedom from worry regarding sludge "bulking."

Thus we have established the principles of a process wherein many of the requirements to solve our problem are achieved.

1. By the addition of digested sludge and the consequent lowering of the sludge index, and also by the use of high solids concentrations in the sludge treatment tank, the solids in the activated sludge system can be maintained at a much higher level than can be attained by the normal activated sludge process.
2. The digested sludge provides a material of greater settleability than the normally produced activated sludge and thereby lowers the sludge index of the activated sludge to which it is added and in which it is incorporated.
3. The use of the sludge treatment tank and the interchange of activated sludge between it and the aeration tanks provides a change in environment from that of adsorption and synthesis in the aeration tanks to one of oxidation in the sludge treatment aeration tanks.
4. The ammonia present in the digested sludge provides the nitrogen considered to be necessary in order to provide a balanced nutrient for the activated sludge organisms.
5. The conversion of the ammonia into nitrate and nitrite nitrogen in the sludge treatment tanks and the subsequent introduction of the oxidized nitrogen into the aeration tanks by the interchange procedure provides an oxygen resource not available in the conventional activated sludge process and possibly inhibits the growth of filamentous organisms.
6. The use of the interchange procedure as a batch or intermittent operation affords substantially two batches of activated sludge in the system and provides a means of rapidly restoring clarifying properties if a "shock" load on the activated sludge in the aeration tanks should destroy this quality. The sludge in the sludge treatment tank will restore the clarifying ability of the activated sludge in the aeration tanks more rapidly than it can be restored in the normal activated sludge process.
7. Regarding the problem of rising sludge in the final settling tanks, this procedure has no beneficial effect. If the interchange is carried out at too high a rate during periods of low load the difficulty may be accentuated. By proper control of the quantity of air it is possible to reduce this condition to such a point that its effect on the suspended solids in the effluent is negligible.
8. The use of this procedure has completely eliminated the sludge bulking problem and the presence or absence of *sphaerotilus* is no longer a matter of immediate concern but rather one of academic interest.

Process Application

Many operating procedures were tried to ascertain the most satisfactory method of using the above stated principles. Batch addition of digested sludge, batch interchange, continuous addition of digested sludge, continuous interchange, low rate interchange and high rate interchange were used in various combinations and it was found under the varying load condition at the plant that the most satisfactory method was one of continuous addition of digested sludge and a low rate interchange made on alternate days. The intermittent interchange was considered more desirable than the continuous interchange due to the desire to separate the activated sludge in the aeration tanks and the sludge treatment aeration tanks into two batches so that if a "shock" load caused loss of clarification in the aeration tank activated sludge on one day, clarifying properties could be rapidly restored by the interchange of the two sludges on the following day.

The plant operating data indicating the complete process as is used at present will be presented in a subsequent paper.

Comments and Conclusions

The process herein presented is not intended as a means of solving perfectly all of the problems of the activated sludge process. Instead it is offered as a means of overcoming some of the difficulties encountered. It must be borne in mind that the use of this process does not alter in any way the fundamentals of the activated sludge process. Its requirements of air, food and proper activated sludge remain unchanged. Its use merely affords a means of control so that the activated sludge process may be carried out more expediently and efficiently.

At Peoria the cost of making the necessary changes to use this procedure was in the order of $500. This low cost, however, was due to the very flexible nature of the plant piping facilities. The process involves no additional cost in operation.

Conclusions drawn from this study may be summarized by the statement that the process as finally worked out has been satisfactory in that it has largely eliminated the plant activated sludge process problems during a period when the load was higher than at any previous time. By controlling the amount of digested sludge used, it is possible to maintain the sludge index of the activated sludge within sufficiently reasonable limits so that it is unnecessary at any time to lose sludge solids in the final effluent due to bulking.

The process affords a perfect means of disposing of supernatant liquor. High solids concentration in digester overflow no longer creates a difficulty in the activated sludge process but rather becomes an asset in that it aids in controlling the process.

Finally, due to the ability to maintain a low sludge index and proper activity in the activated sludge under adverse loading conditions, it is

possible with this process to apply greater loadings to the aeration tanks and higher settling rates to the final settling tanks than in the conventional process.

BIBLIOGRAPHY

1. Mohlman, F. W., "The Sludge Index." *This Journal*, **6**, 119 (1934).
2. Ruehhoft, C. C., Butterfield, C. T., McNamee, P. D., and Wattie, Elsie, "Studies of Sewage Purification. IX. Total Purification, Oxidation, Adsorption and Synthesis of Nutrient Substrates by Activated Sludge." *Ibid.*, **11**, 195 (1939).
3. Heukelekian, H., and Ingols, R. S., "Studies on Activated Sludge Bulking. II. Bulking Induced by Domestic Sewage." *Ibid.*, **12**, 694 (1940).
4. Lackey, James B., and Wattie, Elsie, "Studies of Sewage Purification. XIII. The Biology of Sphaerotilus Natans Kutzing in Relation to Bulking Activated Sludge." *Ibid.*, 12, 669 (1940).
5. Ruehhoft, C. C., and Kachmar, John F., "Studies of Sewage Purification. XIV. The Role of Sphaerotilus Natans in Activated Sludge Bulking." *Ibid.*, **13**, 3 (1941).
6. Sawyer, C. N., "Activated Sludge Oxidations. V. The Influence of Nutrition in Determining Activated Sludge Characteristics." *Ibid.*, **12**, 3 (1940).
7. Ingols, R. S., and Heukelekian, H., "Studies on Activated Sludge Bulking. I. Bulking of Sludge by Means of Carbohydrates." *Ibid.*, **11**, 927 (1939).
8. Ingols, R. S., and Heukelekian, H., "Studies on Activated Sludge Bulking. III. Bulking of Sludge Fed with Pure Substances and Supplied with Different Amounts of Oxygen." *Ibid.*, **12**, 849 (1940).

RISING OF ACTIVATED SLUDGE IN FINAL SETTLING TANKS *

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Rising or floating of activated sludge in final sedimentation tanks is a rather common problem in many plants which utilize this agent in the treatment of sewage. In this country the problem has not received the attention of sewage works men that its importance would indicate. Although many individual operators have admitted trouble with rising sludge, free and frank group discussions have been very limited in number. This may be because the rising sludge problem is most frequently encountered in medium and small size plants where the personnel is less likely to publicize operation troubles. In England, however, discussions have been rather extensive and it is to this source of information that many of us have turned for enlightenment on this problem.

The earliest investigations on the rising sludge phenomenon appear to have been conducted by O'Shaughnessy and Hewitt (1) as reported in 1935. Their investigations led them to conclude that nitrogen gas released in the sludge by reduction of nitrites resulted in buoying the sludge to such an extent that it eventually floated. The interest shown in their paper is evidenced by the discussion of it which occurred at a meeting of the Midland Branch of the Institute of Sewage Purification (2). A paper by J. A. McLachlan on "The Settlement and Rising of Activated Sludge" (3), based on experiences at the Bruma Works of Johannesburg, South Africa, substantiates the findings of O'Shaughnessy and Hewitt and adds information to show that poorly stabilized mixtures of activated sludge and sewage are most prone to rise. The discussion following McLachlan's paper again shows the widespread interest in the problem and the differences of opinion which existed. Bragstad and Bradney (4) made a study of the rising sludge problem at Sioux Falls, South Dakota, and found that the rising sludge was due to gaseous nitrogen, evidently released from nitrites. Wooldridge and Corbet (5) attribute the cause of rising sludge to elemental nitrogen but differ in their conception of its formation.

At this stage of the discussion, it may be well to reiterate that practically all who are acquainted with the rising sludge problem agree that the causative agent is gaseous nitrogen, which buoys the sludge and causes it to float. They are agreed, also, that the phenomenon is one correlated with nitrifying sludges and the presence of nitrites.

Several theories have been advanced to explain the release of free nitrogen from the nitrites present in the activated sludge mixture.

* A special contribution originally intended for presentation at the Eighteenth Annual Meeting and Sixth Annual Convention of the Federation, since postponed.

Briefly, they are as follows:

1. Biological denitrification.
2. Reaction of amino compounds and nitrous acid.
3. Decomposition of ammonium nitrite.
4. Utilization of nitrite for protein synthesis (5).

Since the inception of the investigations to be reported in this paper, three articles have appeared by English investigators concerning the rising sludge phenomenon. Brandon and Grindley (6) have reported on rising sludge problems in preliminary settling tanks when high concentrations of ammonium nitrate were present in the untreated sewage. Wm. T. Lockett (7) has emphasized the importance of eliminating short-circuiting, the prompt removal of sludge from final settling basins and the necessity of allowing aeration periods long enough to produce 8 to 12 p.p.m. of nitrate nitrogen as factors in preventing rising sludge. L. F. Mountfort (8) has reported on difficulties with rising sludge in humus tanks used to settle trickling filter effluent. Difficulties were correlated with the presence of a gas works waste containing high concentrations of ammonium sulfate which resulted in the production of considerably more nitric nitrogen in the final effluent.

Experience at Sioux Falls, South Dakota

Prior to 1936, the sewage treatment facilities at Sioux Falls provided for trickling filter treatment of settled packing house and domestic wastes without benefit of humus tanks. In the spring of 1936, activated sludge units were placed in operation to treat the effluent from the filters. Rising sludge problems resulted shortly thereafter. Various methods of operation were tried by changing the sewage loading on the plant but without success. Relief was finally afforded by maintaining uniform flow to the aeration tanks and by controlling the air supply to keep from 2 to 3 p.p.m. of D.O. in the first half of the aeration tank and not more than 0.5 p.p.m. in the last half. Under this system of control the plant operated rather satisfactorily until it became severely overloaded by increased amounts of industrial wastes. A program of remodeling and enlarging the plant was conducted from 1940 to 1943. New high rate filters of the back-wash type and a clarifier were provided for preliminary treatment of the settled industrial wastes. These and other changes have been described by Hill (9).

Shortly after the new filters were placed in operation, the activated sludge began to rise again and no control measures proved effective. Under winter conditions floating was spasmodic, resulting in the loss of large quantities of activated sludge which had taken several days to accumulate. Under summer conditions floating was continuous and activated sludge was lost so fast that it was impossible to maintain more than 500 p.p.m. of suspended solids in the mixed liquor. B.O.D. and especially suspended solids removals were adversely affected by the low aeration solids concentrations that could be maintained and by the high

suspended solids in the final effluent, caused by the floating sludge. Rising sludge problems were also encountered in the humus tanks used to settle secondary filter effluent.

The flow diagram shown in Figure 1 will aid materially in an understanding of the experimental results to be presented.

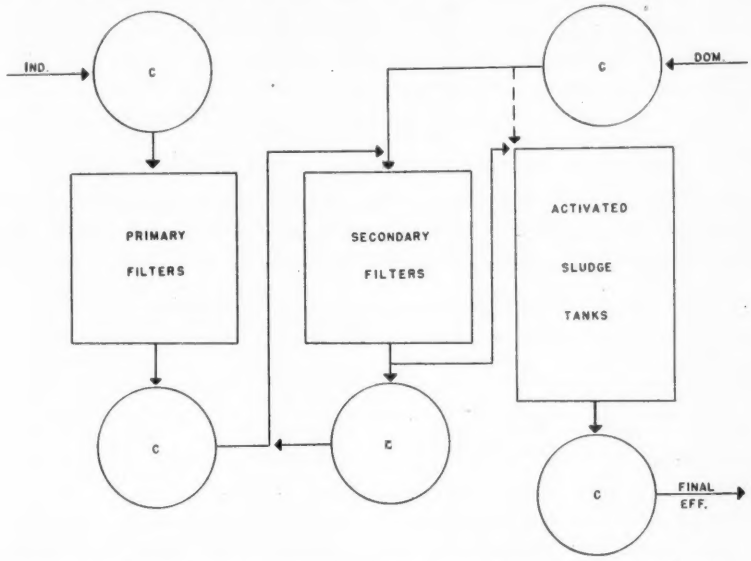

FIGURE 1.—Flow diagram of sewage treatment plant, Sioux Falls, South Dakota.

INVESTIGATIONS OF THE RISING SLUDGE PHENOMENON

Factors Related to the Release of Nitrogen Gas

Two sets of experiments were performed which were designed to yield pertinent information on nitrogen gas formation. The first consisted of allowing a sample of mixed liquor from the aeration tank to settle in order to concentrate the activated sludge. The clear supernatant liquor was siphoned off to separate the sludge from the major portion of its contained inorganic nitrogen compounds, and 100-ml. portions of the concentrated sludge were placed in each of 9 one-liter cylinders. Nine hundred ml. of the siphoned supernatant liquor was placed in one of the cylinders and the others were filled with 900 ml. of tap water, to which had been added ammonia or nitrite or nitrate or combinations of these. All samples were mixed thoroughly with the sludge, the sludges allowed to subside, and rising times noted. The results are given in Table I and show that only the sludges in contact with appreciable quantities of nitrite and/or nitrate floated. The fact that the sludge in contact with nitrate only floated indicates that bacterial reduction is responsible in some degree, as no other explanation seems plausible.

TABLE I.—*Factors Related to the Rising of Activated Sludge*

Cyl. No.	Sludge	Mixture Added	Rising Time (Min.)
1	100 ml.	900 ml. Effluent	77
2	100 ml.	900 ml. Water	>255
3	100 ml.	900 ml. Water + NH_3	>255
4	100 ml.	900 ml. Water + NO_2	84
5	100 ml.	900 ml. Water + NO_3	84
6	100 ml.	900 ml. Water + NH_3 + NO_2	73
7	100 ml.	900 ml. Water + NH_3 + NO_3	87
8	100 ml.	900 ml. Water + NO_2 + NO_3	64
9	100 ml.	900 ml. Water + NH_3 + NO_2 + NO_3	64

A second experiment was performed to obtain information on the importance of bacterial action in producing nitrogen gas, the cause of floating sludge. The results shown in Table II were obtained. These

TABLE II.—*Effect of Disinfecting Agents on Rising of Activated Sludge*

Cyl. No.	Mixture	Treatment	Rising Time (Min.)
1	Mixed Liquor	None	65
2	Mixed Liquor	Phenol	>230
3	Mixed Liquor	Benzol	>230
1	Mixed Liquor	None	70
2	Mixed Liquor	Phenol + NO_2	>1200
3	Mixed Liquor	Benzol + NO_2	>1200
4	Mixed Liquor	$HgCl_2$ + NO_2	>1200

data show that inhibition of bacterial action completely eliminates the rising sludge phenomenon. They also show that large quantities of nitrites in the absence of bacterial action will not cause floating.

Relative Significance of Nitrites and Nitrates

It was deemed pertinent to determine whether nitrites were more conducive to the development of rising sludge than nitrates. Information on this point was obtained by adding nitrites to one sample of aeration mixture, nitrates to another and comparing the rising time with

TABLE III.—*Effect of Added Nitrites and Nitrates on Rising Time of Activated Sludge*

Cyl. No.	Mixture	Rising Time (Min.)
1	Aeration Effluent (low in NO_2 and NO_3)	119
2	Aeration Effluent + nitrites	38
3	Aeration Effluent + nitrates	39

that of a control portion to which nothing was added. The data are presented in Table III and show that the addition of either nitrites or nitrates shortened the rising time and shortened it to about the same extent.

Critical Oxidized Nitrogen Concentration

It having been established that the presence of nitrites and/or nitrates was necessary in the mixed liquor to cause float, the next step was to determine the concentration which could be tolerated without causing trouble. In late November, with the advent of low sewage temperatures and increased plant loadings, the oxidized nitrogen concentration in the aeration effluent dropped so low that rising of the sludge disappeared. Samples of some of the mixed liquor were placed in cylinders and various quantities of oxidized nitrogen added to them. The results, presented in Table IV, show that about 5 p.p.m. of oxidized

TABLE IV.—*Oxidized Nitrogen Concentration Necessary to Cause Float*

Cyl. No.	Mixture in Cylinder	Oxidized Nitrogen in Mixture (P.p.m.)	Rising Time (Min.)
1	M.L.	3.1	>150
2	M.L. + 1 p.p.m. Oxid-N	4.1	>150
3	M.L. + 2 p.p.m. Oxid-N	5.1	110
4	M.L. + 3 p.p.m. Oxid-N	6.1	70
5	M.L. + 4 p.p.m. Oxid-N	7.1	60

nitrogen can be tolerated under conditions which exist at Sioux Falls. Concentrations in excess of this value resulted in floating. Similar experiments were performed on numerous occasions over several months and all showed the critical value to be from 4 to 6 p.p.m.

During the course of the laboratory investigations, an activated sludge was developed from settled domestic sewage. Studies were made on this sludge to determine its critical oxidized nitrogen concentration. The results showed that it required about twice as much (10 p.p.m.) to cause it to rise.

Influence of Temperature on Rising Time

The rising sludge problem is generally much more serious during the summer months and indicates that temperature is an important factor in determining its rate. Over a period of several weeks, studies were conducted to determine the influence of temperature upon the rising time of the sludge. These data are presented in Figure 2 and demonstrate the importance of temperature in the rising sludge problem. The curve shown in Figure 2 may be used to determine the minimum time Sioux Falls activated sludge may be expected to remain in a settled condition. The following minimum time-temperature relationships are indicated for Sioux Falls conditions:

10° C.	93 min.	50° F.
15° C.	72 min.	59° F.
20° C.	51 min.	68° F.
25° C.	30 min.	77° F.

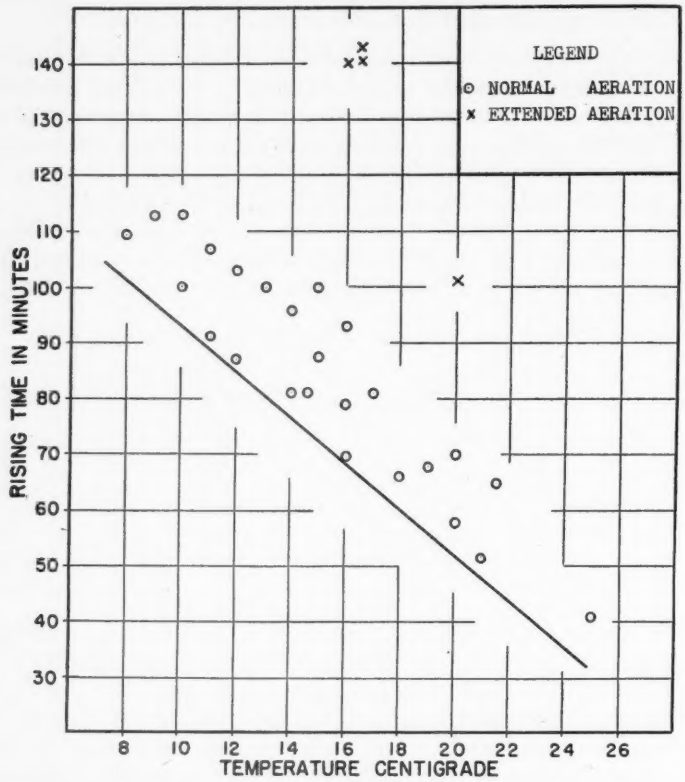

FIGURE 2.—Rising time of activated sludge as influenced by temperature.

Influence of Available Food Supply

(*a*) *Carbonaceous Matter.* In order to determine the effect of an abundant food supply upon the rising time of activated sludge, a sample of aeration tank effluent was used. One portion was used for obtaining the normal rising time of the sludge. The remainder was set-

TABLE V.—*Effect of Added Food Material on Rising Time of Activated Sludge*

Cyl. No.	Mixture	Rising Time (Min.)
1	Aeration Tank Effluent	93
2	Mixed Liquor After 30 Min. Aeration	50
3	Mixed Liquor After 60 Min. Aeration	55
4	Mixed Liquor After 90 Min. Aeration	61
5	Mixed Liquor After 2 Hrs. Aeration	63
6	Mixed Liquor After 3 Hrs. Aeration	64

tled to separate the activated sludge and then fed with fresh sewage and kept under aeration. At intervals of 30 or 60 minutes, samples of the aeration mixture were taken to determine rising time of the sludge. The data obtained are given in Table V and show that the presence of a plentiful food supply markedly shortens the rising time of the sludge

and that the rising time is very gradually lengthened with continued aeration. Even after 3 hours aeration, the sludge had not regained a rising time of 93 minutes which it had before being fed.

It has been recognized by certain British investigators that short-circuiting in aeration tanks tends to aggravate a rising sludge condition. The above data would substantiate such a contention and lead to the conclusion that all reasonable steps should be taken to reduce short-circuiting to a minimum. To obtain further proof of this point, an experiment was performed with an aeration mixture wherein 2 one-liter samples were withdrawn at each 30-minute interval after the start of aeration and 150 ml. of untreated sewage were added to one of the samples to simulate conditions of short-circuiting. Both were then shaken and allowed to settle to determine the rising time. The data are given in Table VI and show that the rising time may be reduced appreciably by short-circuiting.

TABLE VI.—*Effect of Short-Circuited Sewage on Rising Time*

Time of Aeration (Hrs.)	Rising Time (Minutes) Ideal Conditions	Short-circuited Conditions
0.0	62	—
0.5	67	64
1.0	70	66
1.5	94	71
2.0	93	79
2.5	99	79
3.0	95	84
3.5	98	83
4.0	101	87
5.0	106	85

(*b*) *Nitrogenous Matter.* Since the rising sludge phenomenon was found to be so critically related to the presence of nitrites and nitrates in the mixed liquor, the question naturally arose as to whether complete nitrification might not delay the rising time. Consequently, parallel studies of nitrification and rising time were made upon a mixture of activated sludge and sewage (secondary filter effluent). The data obtained in this study are given in Table VII and show that an appreciable delay in rising time was correlated with the completion of nitri-

TABLE VII.—*Influence of Complete Nitrification on Rising Time.* (Results in p.p.m.)

Time of Aeration (Hrs.)	Nitrogen in Mixed Liquor			Rising Time (Min.)
	NH_3–N	NO_2–N	NO_3–N	
0.0	11.0	2.20	14.2	62
0.5	4.8	5.20	17.6	67
1.0	0.3	5.50	22.2	70
1.5	0.2	1.97	25.5	94
2.0	—	0.20	26.9	93
2.5	—	0.12	27.6	99
3.0	—	0.10	27.6	95

fication, as indicated by the low ammonia and nitrite nitrogen values at the time.

Bacteriological Investigations

Studies on Pseudomonas fluorescens

At the start of the investigations, it was generally believed by those responsible for its direction that the rising sludge problem was intimately related to biological reduction of nitrites and nitrates present in the sludge mass, resulting in liberation of free nitrogen gas which buoyed the sludge when sufficient quantities had been released. The biological reduction or denitrification was believed to be the work of certain denitrifying bacteria. It had been reported to us that *Pseudomonas fluorescens,* a denitrifying bacterium, was an important inhabitant of activated sludge. Recent developments in the food industry, where *P. fluorescens* is a primary invader of eggs, have shown that their presence may easily be detected by the use of black light (ultraviolet) when suitable provisions are made in the medium upon which they are grown. With such an easy means of detection available it was felt that studies on this organism might lead to finding a source of infection with these denitrifying organisms which, if eliminated, might overcome the proclivity of the activated sludge to rise.

Studies were inaugurated for the detection of *P. fluorescens* in all the wastes receiving biological treatment in the plant, in the activated sludge, and in the final effluent. These studies were made on five different occasions and only one colony among the many thousands studied showed fluorescent properties. Question was immediately raised concerning the nature of the medium used in culturing the organisms as to whether it had any particularly toxic properties. Subsequent studies using a pure culture furnished by Dr. L. B. Jensen of Swift & Co., Chicago, Ill., and using cultures isolated from soil showed the absence of inhibitory substances for the development of fluorescence in the medium which was used.

Studies on Denitrifying Organisms in General

In spite of the failure to detect the presence of *P. fluorescens* in the activated sludge, it was considered important to gain some knowledge concerning the numbers of denitrifying organisms in the sludge. Buchanan and Fulmer, in their text on "Physiology and Biochemistry of Bacteria," I, p. 433, state that "Many bacteria . . . are able to reduce nitrites to free nitrogen. . . . In general all attack proteins vigorously. . . ." This statement seemed especially pertinent in the case at Sioux Falls because one of the main functions accomplished in the course of sewage treatment is the stabilization of large quantities of organic nitrogen compounds (mainly proteins) contributed by the packing house industry.

A liquid medium containing nitrites and nitrates was developed for the detection and estimation of the numbers of denitrifying organisms

present in sewage and activated sludge. Its application or use was quite similar to the lactose broth test used for the detection and enumeration of colon-aerogenes group organisms in water analysis. In the test used, the production of nitrogen gas showed the presence of the organisms and serial dilutions allowed calculation of the Most Probable Number. A number of runs were made to determine the M.P.N. of denitrifying organisms present at various stages in the treatment process. The results are tabulated in Table VIII. These studies show

TABLE VIII.—*M.P.N. of Denitrifying Organisms in Sewage at Various Stages in the Treatment Process*

Date	M.P.N. per Milliliter					
	Settled Domestic	Settled Industrial	Pr. Filt. Effluent	Sec. Filt. Effluent	Aeration Mixture	Final Effluent
Oct. 14	24,000	70,000	70,000	70,000	70,000	2,400
23	—	—	—	130,000	1,000,000	—
Nov. 6	—	—	—	130,000	620,000	—
8	—	—	—	230,000	210,000	—
Dec. 7	—	—	—	23,000	210,000	—
11	—	—	—	—	920,000	—

that rather large numbers of denitrifying organisms are native in the settled domestic and industrial wastes, approximating one per cent of the total count. The number contained in the secondary filter effluent and aeration mixture is much larger and may constitute a large percentage of the total numbers—as high as 23 per cent was indicated. Further studies on these organisms were not made, as it was considered that their isolation and identification was more of academic than of practical interest.

STUDIES ON INHIBITION OF NITRIFICATION

Copper Sulfate

(*a*) *Addition of Copper Sulfate to Sewage.* These studies were made with secondary filter effluent (industrial plus domestic) which is the normal aeration tank influent during the winter months, using concentrations of copper sulfate yielding from 2 to 10 p.p.m. of copper. The experiments were run on a fill and draw basis and copper sulfate was added in proper quantity to each new portion of sewage fed. The experiments were conducted for a period of 10 days and the results obtained on the tenth day, as shown in Table IX, illustrate what can be accomplished by such a method of treatment.

The data show that copper sulfate is more effective in controlling nitrate formation than nitrite formation and that at least 5 p.p.m. would be required on a continuous basis. As much as 8 p.p.m. would be required to control nitrite formation. Inhibition of sludge rising was not obtained until the formation of oxidized nitrogen was nearly stopped.

TABLE IX.—*Effect of Adding Copper Sulfate to Sewage in Controlling Nitrification and Rising Sludge.*
(Results in p.p.m.)

Sludge No.	Oxidized Nitrogen in Effluent		Rising Time (Min.)
	NO_2–N	NO_3–N	
*0	0.20	46.0	101
2	0.20	44.2	70
3	0.08	44.2	74
4	0.10	39.4	78
5	75.0	5.4	70
6	75.0	1.4	43
8	7.0	0.0	>180
10	3.5	0.0	>180

* Denotes p.p.m. of copper in the sewage fed.

This indicates that copper sulfate has little control over denitrifying organisms. Further investigations on adding copper sulfate to sewage were not performed, because the addition of 8 or even 5 p.p.m. of copper to the sewage was not considered economically sound.

In order to determine whether the activated sludges produced from sewages containing copper sulfate might interfere with destruction of the sludge by digestion processes, the activated sludges remaining at the end of the above mentioned experiment were analyzed for their copper contents. The results are given in Table X and indicate that much of the copper is retained in the sludge and would, no doubt, interfere seriously with disposal of excess sludge by digestion processes.

TABLE X.—*Copper Content of Activated Sludges Produced from Sewages Containing Copper Sulfate*

Sludge No.	Milligrams of Cu per Kilogram
*0	190
2	2,500
3	4,300
4	7,500
5	8,000
6	9,500
8	13,500
10	15,500 or 1.55%

* Denotes p.p.m. of copper in the sewage fed.

(*b*) *Shock Treatment of Activated Sludge with Copper Sulfate.* The question was raised as to whether intermittent treatment of return activated sludge with rather large doses of copper sulfate might not suffice to control nitrification and render the method economically feasible. Consequently, a series of tests was run treating the return sludge with 15 and 20 p.p.m. of copper at 5-day intervals. After the experiment had been conducted for 17 days and the sludges had received four treatments with copper sulfate, samples of the effluents were taken for analysis and the rising times of the sludges were determined, as shown in Table XI. These data show that copper sulfate treatment mate-

rially interferes with stabilization of the sewage, as indicated by the high organic nitrogen and B.O.D. values of the effluents obtained from the sludges treated with 15 and 20 p.p.m. of copper. They again show that copper sulfate treatment gives fair control over nitrate formation but little control over nitrite production and denitrification, thus yielding no relief from the rising sludge problem.

TABLE XI.—*Character of Effluents Produced by 5-Day Shock Treatment of Activated Sludge with Copper Sulfate.* (Results in p.p.m.)

Sludge	Nitrogen				B.O.D.	Rising Time of Sludge (Min.)
	NH_3–N	Org–N	NO_2–N	NO_3–N		
Control	0.40	2.75	0.16	37.2	7	97
*15	0.40	6.25	38.2	9.2	37	76
20	0.40	7.50	49.6	2.7	23	72

* Denotes p.p.m. of copper added to return sludge.

(*c*) *Studies with Ferrous Sulfate (Copperas).* It had been reported that the presence of ferrous sulfate in sewage would inhibit nitrification. Consequently, a series of feeding experiments were made in which copperas was added to the mixed liquor in concentrations to furnish 10, 20 and 30 p.p.m. of iron. Additions were made every fourth day. At the end of 13 days, the following results were obtained on the effluents produced. The data in Table XII show that no inhibition of nitrite or nitrate formation occurred and that only small benefits could be expected in delayed rising time of the sludge.

TABLE XII.—*Character of Effluents Produced by Ferrous Sulfate Additions to Aeration Mixture at 4-Day Intervals.* (Results in p.p.m.)

Sludge	Nitrogen				Rising Time of Sludge (Min.)
	NH_3–N	Org–N	NO_2–N	NO_3–N	
Control	0.60	6.25	9.0	30.8	97
Fe–10	—	—	10.8	30.0	91
Fe–20	0.40	6.50	9.0	30.0	102
Fe–30	0.40	5.75	5.8	31.0	112

(*d*) *Studies on Chlorination.* Chlorine has been rather extensively used in the sewage treatment field. In connection with activated sludge plant operation, it has enjoyed the reputation of somewhat of a "cure-all," but not much information on the mechanism of its actions is available. It was deemed advisable to study its effectiveness in the control of nitrification. Feeding experiments were run in which the return sludge was chlorinated before each feeding, using 4, 7 and 10 p.p.m. Typical results are shown in Table XIII. These data show that both nitrite and nitrate formation were inhibited by chlorination, since no appreciable increase occurred in their concentration over that contained

in the filter effluent used for feed. The longer rising time shown by the sludges treated with 7 and 10 p.p.m. of chlorine indicate that some inhibition of denitrification may have resulted. The high organic nitrogen and B.O.D. values show that the purifying ability of the activated sludge had been seriously impaired.

TABLE XIII.—*Effect of Chlorination of Return Sludge on Nitrification by Activated Sludge.* (Results in p.p.m.)

Sludge	Nitrogen in Effluent				Effluent B.O.D.	Rising Time of Sludge (Min.)
	NH_3–N	Org–N	NO_2–N	NO_3–N		
Control	15.0	3.85	17.0	17.6	6	96
Cl–4	37.5	8.60	*3.3	*10.7	26	96
Cl–7	39.0	11.3	3.5	9.5	50	120
Cl–10	38.9	11.6	3.4	9.2	65	180

* Secondary filter effluent used to feed sludges contained about 3 p.p.m. of NO_2–N and 10 p.p.m. NO_3–N.

(*e*) *Chromates as Inhibiting Agents.* No studies were conducted using chromates as the work of Jenkins and Hewitt (10) has shown them to produce unsatisfactory treatment when present in large enough concentrations to control nitrification.

(*f*) *Studies with Alpha-Naphthoquinone.* Alpha-naphthoquinone is a waste product in the manufacture of certain organic chemicals. It has been reputed to have bacteriostatic properties toward certain bacteria. Its ability to inhibit nitrification by activated sludge was investigated, using 10 and 20 p.p.m. in the feed mixture. The studies showed no restriction in these concentrations.

TABLE XIV.—*Effect of Adding Digested Sludge on Nitrification.* (Results in p.p.m.)

Sludge	Nitrogen				Rising Time of Sludge (Min.)
	NH_3–N	Org–N	NO_2–N	NO_3–N	
Control	0.50	3.80	0.35	32.9	95
*5	0.40	4.20	0.37	50.4	115
10	0.40	5.20	0.30	68.8	120
20	57.80	8.80	34.30	12.8	130

* Denotes per cent by volume of digested sludge in return sludge.

(*g*) *Studies on Nacconol-NR.* Nacconol-NR is one of the modern detergents which have been developed for use in hard waters. Some of these have shown definite germicidal and cysticidal properties. Feeding experiments were conducted using 10 and 20 p.p.m. of Nacconol in the sewage used. The results obtained showed no control over nitrite formation and very poor inhibition of nitrate formation or of denitrification.

(*h*) *Studies on Digested Sludge.* Addition of digested sludge to activated sludge has been reported as having some beneficial effects in activated sludge control. One series of studies was made in which the return sludge consisted of 5, 10 and 20 per cent of digested sludge on a volume basis, or 14.3, 20.0 and 28.5 per cent on a solids basis. The results obtained on the seventh day of the experiment indicate what benefits can be expected from such treatment. These data show that concentrations of digested sludge as great as 10 per cent by volume of return sludge had no effect in controlling nitrification. Additions of 20 per cent reduced the amount of nitrates formed but allowed considerable nitrite formation. Rising time was delayed materially which seemed to be the only beneficial effect.

A second run was made in which digested sludge was added at 4-day intervals to give mixed liquor solids containing 25, 35 and 45 per cent of digested solids. The results obtained were essentially the same as those shown for the first experiment.

Investigations on Lowering of Oxidized Nitrogen Concentrations Below Critical Values

Mechanical Flocculation

Most of the trouble relating to rising sludge at the Sioux Falls plant is correlated with the periods of the year when the secondary filters produce considerable quantities of oxidized nitrogen, thus nullifying any control measures used in the activated sludge units. Even if no further nitrification occurred in the aeration units, the secondary filter effluent could easily supply oxidized nitrogen concentrations in excess of the critical value of 5 p.p.m. It seems reasonable to assume that substitution of mechanical flocculators for all or part of the aeration facilities in the activated sludge units during such seasons might allow a method of operation to be developed wherein enough denitrification might occur to reduce the oxidized nitrogen concentration below the critical value.

Laboratory studies on denitrification were made with mechanical flocculation and with stirring with nitrogen gas to simulate plant conditions with mechanical flocculators. Studies with secondary filter effluent alone (normal aeration tank feed) showed that little reduction of oxidized nitrogen concentration occurred in periods of 6 to 8 hours, indicating that the secondary filter effluent did not possess enough residual carbonaceous B.O.D. to accomplish the objective. Similar studies were made with secondary filter effluent fortified with various food materials (glucose, peptone, and untreated sewage) and complete dissipation of the oxidized nitrogen was obtained in as short a time as 4 hours. This indicated that addition of some untreated sewage to the secondary filter effluent could provide enough food material to accomplish denitrification when mixed and flocculated with activated sludge.

Activated sludge feeding studies were conducted in which a 50–50 mixture of secondary filter effluent and settled domestic sewage was fed to the sludges thrice daily, allowing a 6-hour period between feedings.

Three possibilities of operation were investigated in the experiments:

1. Three hours mechanical flocculation followed by 3 hours aeration.
2. Three hours aeration followed by 3 hours mechanical flocculation.
3. Mechanical flocculation for 6 hours.

Results typical of those given in each experiment are given in Table XV. These data show that good B.O.D. and organic nitrogen removals can be obtained by substituting mechanical flocculation for part or even all of the aeration period. Nitrification was controlled to vary-

TABLE XV.—*Studies on Substitution of Mechanical Flocculation for Aeration in Activated Sludge Treatment of Secondary Filter Effluent plus Settled Domestic Sewage.* (Results in p.p.m.)

Conditions	Nitrogen in Effluents				Effluent B.O.D.	Rising Time of Sludge (Min.)
	NH_3–N	Org–N	NO_2–N	NO_3–N		
M.F. + A.	32.7	6.00	5.25	0.76	15.5	>200
A. + M.F.	31.4	5.00	7.60	5.90	12.5	70
M.F.	37.4	4.50	0.16	0.00	13.0	>200
A.	24.6	4.20	11.40	13.80	7.5	96

M.F. = Mechanical flocculation. A. = Aeration.

ing degrees. In the case of mechanical flocculation alone, the oxidized nitrogen was practically exhausted and the sludge never showed any tendency to rise. When mechanical flocculation was followed by 3 hours of aeration, the sludge did not float because the oxidized nitrogen concentration had been lowered to below its critical value. In the other cases, sufficient oxidized nitrogen was present at the end of the cycle to float the sludge. It should be mentioned that the sludge which received no aeration showed a slight tendency to "bulk" during the latter part of the experiment. This condition was probably a result of complete disappearance of the oxygen reserves. The other sludges receiving mechanical flocculation did not show this tendency. It would appear, therefore, that reduction of oxidized nitrogen concentrations

TABLE XVI.—*Effect of Diluting Aeration Tank Effluent with River Water on Rising Time of Activated Sludge*

Cylinder	Per Cent Composition		Oxidized Nitrogen (P.p.m.)	Rising Time of Sludge (Min.)
	Mixed Liquor	River Water		
1	100	0	10.9	70
2	80	20	8.9	75
3	70	30	7.8	78
4	60	40	6.8	87
5	50	50	5.8	*147
6	40	60	4.8	>300
7	30	70	3.8	>300

* Sample did not float but peeled badly.

below critical values but not to the point of extinction, by a combination of mechanical flocculation and aeration, may be a reasonable method of operation to overcome the rising sludge problem. Such a practice would require close 24-hour control, however.

Dilution with River Water

The river water at Sioux Falls usually contains somewhat less than 1 p.p.m. of oxidized nitrogen. The concentration of oxidized nitrogen in the activated sludge mixture flowing to the final settling tanks could be materially decreased by adding river water to it. An experiment was run to determine how effective such treatment would be. The results are presented in Table XVI. These data again show that floating of the activated sludge can be controlled by reducing the oxidized nitrogen to below critical concentrations. A 50–50 mixture with river water will suffice providing the oxidized nitrogen concentration in the aeration tank effluent does not exceed 10 p.p.m. Additional clarifier capacity would probably be required.

Extended Aeration Periods as a Means of Controlling Rising Sludge

Plant scale tests were run during the latter part of April and early May to determine whether appreciable delay in the rising time of the sludge could be brought about by long aeration periods. The data obtained are given in Table XVII and show that practically complete con-

Table XVII.—*Effect of Extended Aeration Periods on Sludge Rising Time and Nitrification.*
(Aeration Period 12 Hrs.) (Results in P.p.m.)

Date	Nitrogen in Effluent				Susp. Solids in M.L.	Rising Time (Min.)
	NH_3–N	Org–N	NO_2–N	NO_3–N		
April 24	24.8	5.75	4.34	23.4	—	70
25	20.0	4.75	4.95	25.3	716	60
26	12.0	4.00	7.00	30.9	884	72
27	4.25	5.00	8.10	38.0	888	—
28	1.50	5.00	5.64	47.5	1300	70
29	0.35	3.80	0.53	55.8	—	—
30	0.75	4.50	1.32	54.5	1360	105
May 1	0.25	5.25	0.61	44.1	1324	103
2	1.00	4.25	0.98	39.9	1476	105
3	2.25	6.75	2.20	47.5	1560	75
4	4.50	8.00	6.00	42.6	1396	64
5	0.75	7.25	3.50	49.3	1252	70
6	0.75	6.25	0.45	45.8	—	—
7	0.50	6.00	0.45	48.5	1512	100

version of ammonia and nitrite to nitrate must be accomplished before an appreciable extension in rising time of the sludge can be expected. A comparison of rising times with extended and with regular aeration periods is shown in Figure 2.

Final Clarifier Operation

This discussion of the rising sludge problem at Sioux Falls would not be complete without some mention of the importance of rapid removal of activated sludge from final sedimentation tanks. Generous rates of return sludge, averaging approximately 40 per cent, have been used at Sioux Falls to favor the return of a fresh sludge and prevent the accumulation of sludge blankets. Attention was first focused on the final clarifier mechanisms when studies on suspended solids in the influent and return sludge showed compaction ratios of approximately 2.0. Even with reduced rates of return sludge, compaction ratios of more than 3.0 were difficult to obtain. Since laboratory tests indicated a compaction ratio of 5.0 could be obtained in 30 minutes settling, there was cause for suspicion of short-circuiting in the final tanks.

During December and January when low temperatures and high organic loadings were limiting nitrification to concentrations which would not cause the sludge to rise, a series of studies were made to determine depth and concentration of solids in the sludge blanket. Depths in excess of four feet and sludge concentrations in excess of 19,000 p.p.m. were measured with normal rates of return sludge. The solids concentrations encountered indicated that some of the sludge had been in the tanks as long as 8 hours. Calculations based on the suspended solids in the sludge blanket near the sludge removal port, in the return sludge and in the tank influent indicated the return sludge to consist of approximately 80 per cent of short-circuited mixed liquor.

With the above information at hand, a decision was made to replace the final clarifier mechanisms with a type which promises more rapid and positive removal of the sludge. Installation is expected to be completed in August, 1945.

The floating sludge problem in the humus tanks used to settle secondary filter effluent is related to the slow rate at which the mechanisms move the sludge to the center of the tank. Calculations show that it requires from 2.0 to 2.5 hours for sludge to be transported from the periphery of the tank to the center draw-off well. This is much too long as the trickling filter humus has rising characteristics quite like those of the activated sludge. Since the effluent of these clarifiers is recirculated to the filters, poor removal of solids is not a serious matter and no change of mechanisms is contemplated at this time. The importance of rapid and positive removal of sludge is again demonstrated, however.

Discussion

Nutritional Aspects of the Rising Sludge Problem

The rising sludge problem is related to the presence of nitrites and/or nitrates in the sludge mixture. In most cases the presence of these oxidized forms of nitrogen is a result of the nitrifying ability of sludges. It has been shown by Sawyer (11) that the nitrifying ability of an activated sludge is dependent in some degree upon the relation-

ships which exist between B.O.D. and nitrogen in the sewage feed. With high B.O.D. to nitrogen ratios, non-nitrifying sludges tend to develop and, with low B.O.D. to nitrogen ratios, nitrifying sludges can be expected to form. Just what the critical ratios are has not been determined for any given set of conditions, nor has the relative significance of ammonia and organic nitrogen been determined.

It is the contention of the authors that the rising sludge problem is most severe where sewages with low B.O.D. to nitrogen (carbon to nitrogen) ratios are being treated. It is also contended that the problem is more prevalent in plants where preliminary settling of sewage is practiced, especially when so-called hard water supplies are involved. Such treatment affects the nitrogen content of sewage very little but may cause drastic reductions in the B.O.D. At Sioux Falls, which has a very hard water supply (500 + p.p.m.), the domestic wastes have a B.O.D. to nitrogen ratio of approximately 7.5 and the settled domestic wastes have a ratio of approximately 4.0. This marked change in ratios is due, no doubt, to efficient sedimentation plus grease and soap removal which is favored by the hard water, as B.O.D. removals of 50 to 70 per cent are common.

The high organic nitrogen content of animal packing house wastes makes them especially difficult to treat by biological methods. The stabilization of protein matter by activated sludge results in relatively little growth of the sludge and indicates that much oxidation occurs with concurrent release of ammonia. Long periods of aeration are necessary to accomplish reasonable B.O.D. and organic nitrogen removals and such conditions are conducive to the development of nitrifying conditions.

Critical Oxidized Nitrogen Concentrations

The difference in oxidized nitrogen concentrations found necessary to float activated sludge developed from normal aeration tank feed (5 to 6 p.p.m.) and from settled domestic sewage (10 p.p.m.) merits further discussion. There appear to be two possible reasons for this difference. Sludge density may be one factor. The sludge having the lowest critical value had a sludge index of approximately 150 while the other sludge had an index of 54. It would seem logical to conclude that the most nitrogen gas would be required per unit volume of sludge to float the heavier sludge. On the other hand, the reduction of nitrites may not follow the same course in the two sludges and one may be capable of releasing more nitrogen gas from a given quantity of nitrites than the other. From such a mixed flora as exists in activated sludge, almost anything can be expected to happen.

Inhibition of Nitrification

Attempts to control nitrification or denitrification by the use of inhibiting agents, when successful, all resulted in marked deterioration of the quality of the effluent produced. In general, it may be concluded that the organisms which flourish in a given activated sludge do so be-

cause of a plentiful food supply and because of conditions which are favorable for their development and multiplication. When conditions are made unfavorable for the development of certain organisms, their work of stabilization will be arrested and incomplete treatment will result. No doubt, this factor is of considerable importance when the activities of the denitrifying organisms are interfered with, as they are supposed to be largely responsible for the stabilization of organic nitrogen compounds. In the treatment of wastes as rich in organic nitrogen compounds as those at Sioux Falls, any interference with their stabilization will result in unsatisfactory treatment. It is more difficult to see how inhibition of nitrification may have a deleterious effect on the stabilization of sewage, but at Sioux Falls such seems to be the case. In the absence of nitrifying organisms, ammonia is an end-product of the stabilization of organic nitrogen compounds, and in high concentrations it is known to be a hindrance to the development of certain organisms. The constant removal of the end-product, ammonia, by nitrifying organisms would tend to prevent its building up to unfavorable concentrations and thus allow normal rates of stabilization to proceed.

There is some basis for believing that certain of the denitrifying organisms prefer to obtain their oxygen from nitrates, even in the presence of plentiful supplies of dissolved oxygen. In this case it would seem that nitrification is a necessary adjunct to rapid stabilization of organic nitrogen compounds, and would be another reason why good purification and nitrification go hand-in-hand at Sioux Falls.

Summary

1. Rising of activated sludge has been shown to be correlated with the presence of nitrites and/or nitrates.

2. Evidence is presented to support the contention that biological denitrification of the nitrates to nitrites and then to nitrogen gas results in buoying the sludge when sufficient quantities have formed.

3. One activated sludge was found to tolerate up to 5 p.p.m. of oxidized nitrogen without floating and another was found to tolerate up to 10 p.p.m.

4. Temperature and available food supply were found to be important factors in determining the rising time of activated sludges.

5. Substances inhibitory to nitrifying and denitrifying organisms caused the production of unsatisfactory effluents because of poor B.O.D. and organic nitrogen removals.

6. Denitrifying bacteria were found to represent a considerable percentage of the bacterial population of activated sludge.

7. Extended aeration periods to accomplish complete conversion of ammonia to nitrites and nitrates were found necessary to extend the rising time appreciably.

8. Final clarifier operation was found to be a most critical factor in controlling rising sludge. Collection and removal in periods as short as 30 minutes is indicated.

Conclusions

The following lines of attack are believed to be justified in conquering a rising sludge problem; they are listed in what are considered to be their order of importance:

1. Provide final clarifier mechanisms which will give positive removal of the sludge within the minimum time limit imposed by the sludge.
2. Control nitrification to prevent development of oxidized nitrogen concentrations in excess of the critical value.
3. Dissipate oxidized nitrogen concentrations by mechanical flocculation or dilution.
4. Extend aeration periods to accomplish complete nitrification.
5. Adjust the B.O.D. to nitrogen ratio in sewage by adding carbonaceous matter, eliminating primary sedimentation, etc.

Acknowledgments

The authors wish to express appreciation of the suggestions and counsel freely given by Mr. K. V. Hill and Dr. F. W. Mohlman. Our thanks are due Major Glen J. Hopkins, Sanitary Engineering Division, South Dakota State Board of Health, and Mr. Bert T. Yeager, Commissioner, City of Sioux Falls, for permission to publish the results of investigation.

References

1. O'Shaughnessy, F. R., and Hewitt, C. H., "Phenomena Associated with the Role of Nitrogen in Biological Oxidation." *Jour. Soc. Chem. Ind.*, **54**, 167 (1935).
2. Discussion of (1), Inst. Sew. Purif., *Jr. & Proc.*, 231 (1936).
3. McLachlan, J. A., "The Settlement and Rising of Activated Sludge." Inst. Sew. Purif., *Jr. & Proc.*, 49 (1936).
4. Bragstad, R. E., and Bradney, L., "Packinghouse Waste and Sewage Treatment at Sioux Falls, S. Dak." *This Journal*, **9**, 959 (1937).
5. Wooldridge, W. R., and Corbet, A. S., "The Nitrogen Cycle in Biological Systems." *Biochem. Jour.*, **34**, 1026 (1940).
6. Brandon, T. W., and Grindley, J., "Effect of Nitrates on the Rising of Sludge in Sedimentation Tanks." *Surveyor*, **104**, 7 (1945).
7. Lockett, W. T., "The Phenomenon of Rising Sludge in Relation to the Activated Sludge Process." *Surveyor*, **104**, 37 (1945).
8. Mountfort, L. F., "Some Experiences with Rising Sludge in Humus Tanks." *Surveyor*, **104**, 65 (1945).
9. Hill, K. V., "Sioux Falls, S. D., Sets Its Sewage Plant in Order." *American City* (1944).
10. Jenkins, S. H., and Hewitt, C. H., "The Effect of Chromium Compounds on the Purification of Sewage by the Activated Sludge Process." Inst. Sew. Purif., *Jr. & Proc.*, 222 (1942).
11. Sawyer, C. N., "The Influence of Nutrition in Determining Activated Sludge Characteristics." *This Journal*, **12**, 3 (1940).

CONTROL OF SLUDGE INDEX BY CHLORINATION OF RETURN SLUDGE*

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Synopsis

An investigation was carried on for a period of three years at several Army sewage treatment plants to determine: (a) the possibility of controlling the sludge index by chlorination of the return sludge, (b) the method of control, (c) the dosage necessary.

Data from three particular plants are presented. These plants were selected because of their geographical location, their excellent laboratory facilities and their general similarity.

It was found possible to control the sludge index by chlorination of the return sludge and a method of applying and determining the approximate dosage needed was discovered.

A theory of the action of the chlorine is presented.

The principles involved, while being established at Army plants, have since been applied at several plants treating municipal sewage and the original results corroborated.

History of Chlorination of Activated Sludge

Over a period of years many attempts, some successful, some not, have been made to use chlorine for the control of sludge index in activated sludge plants. It has been reported by Smith and Purdy (1) that "bulking of activated sludge may be caused by diffuse floc structure, fungus growth, or a combination of both" and that chlorine can be successfully used to control that caused primarily by fungus growths. Results exactly opposite to these have been reported by Ridenour, Henderson and Schulhoff (2) when they stated that "chlorine applied to the return sludge had no effect toward increasing the sludge index" (Donaldson), and that "the filamentous character of the sludge remained unchanged." Due to these contradictory reports, and others, there is considerable doubt as to the effectiveness of chlorination as a control of sludge index. It has been suggested that part of the disagreement may be due to differences in the character, or chlorine consuming capacity, of the fungus causing bulking; this, however, remains to be proven.

In the past three years chlorination for the control of sludge index has been successfully practiced by the author at several plants. Particular work was performed at three widely separated Army treatment

* The material for this paper was obtained from a thesis originally presented to the Case School of Applied Science in July, 1944, under the title "Control of Bulking by Chlorination at Army Sewage Treatment Plants," in partial fulfillment of the requirements for the professional degree of Civil Engineer.

plants and it is hoped that this paper, which is essentially a report on this work, will help to clarify to some degree, the present clouded attitude toward this means of control.

Much of the present doubt is caused by the various definitions, or individual interpretation, of what constitutes bulked sludge. It is generally agreed that sludge is bulked when the volume of a unit weight of sludge increases abnormally as indicated by the sludge index, S.I. = Per Cent Settleable Solids/Per Cent Suspended Solids (3). What, however, is an abnormal increase? Some operators consider the sludge bulked when the index reaches 100, others are not concerned until it

TABLE 1.—*Operation Data at Six Activated Sludge Plants*

Plant	Type	Design Flow (M.g.d.)	Present Flow (M.g.d.)	Susp. Solids, Mixed Liquor (P.p.m.)	Sludge Index	B.O.D. (P.p.m.)			Susp. Solids (P.p.m.)			Period of Data*
						Raw	Pri.	Fin.	Raw	Pri.	Fin.	
Belvidere, Illinois	M	1.180	1.077	573	469	211	112	4	241	109	3	5 Yrs.
Bryan, Ohio	M	.864	.720	744	451	129	75	10	137	69	11	5 Yrs.
Canton, Illinois	M	1.050	.718	530	141	216	76	7	287	64	3	5 Yrs.
Lake Charles, Louisiana	D	1.100	1.202	1456	158	212	140	10	287	106	7	4 Yrs.
Marion, Indiana	D	4.000	3.410	2502	78	203	130	14	264	113	14	5 Yrs.
Army Camp	D	.750	.560	853	271	255	170	13	225	107	11	3 Yrs.

* All data are averages of daily analyses for the periods indicated.
M—Indicates mechanical aeration.
D—Indicates diffused air.

reaches 600. Many say the sludge is bulked when the blanket rises in the final tank, when this phenomenon may be due to purely physical or mechanical characteristics of the tank. Obviously, there is no definite sludge index by which all operators can be guided. The sludge index is variable at every activated sludge plant and is dependent upon: (a) the physical characteristics of the plant, (b) the strength and character of the sewage, (c) the concentration of solids in the mixed liquor, (d) the rate of return sludge.

Table 1 gives operation data for six activated sludge plants for an average period of four years. Three of the plants use mechanical aeration and the mixed liquor concentration in these plants is fairly uniform. The sludge index, however, ranges from 141 to 469 with good treatment being obtained at each plant. The mixed liquor concentration in the three diffused air plants ranges from 853 p.p.m. to 2,502 p.p.m., with the sludge index varying from 78 to 271. Each of these plants is also doing a good job with overall results about equal. Yet

Marion, Indiana, operating at an index of 78, would in all probability consider the sludge bulked at an index of 257 which an Army plant finds normal. It is apparent that the term "bulked sludge" means something different to every operator using the term. This is shown by all previous reports regarding chlorination of return sludge in which bulking has occurred at various indices depending upon the individual interpretation of the term. It is entirely possible that much of the doubt regarding this control is due to these variations. The only way an operator can determine a bulking index is to have records for his plant for a considerable period of time when operation was stabilized, and a normal index thus determined. Any abnormal increase of this figure, provided all other variables remain the same, can then be assumed to be a bulking index.

Problems of Design and Operation in Army Sewage Treatment Plants

In 1940, when the problem of sewage treatment plant design for Army camps developed, there was very little known about the strength of Army sewage, per capita flow, or daily flow characteristics. Accurate knowledge of all these factors is essential to adequate design and the lack of this knowledge coupled with rapidly changing conditions led to the construction of many plants which proved difficult to operate. During this initial period of construction it was not unusual to have the design population changed several times while the plants were on the "board" and in some cases the plants were entirely completed when the camp size was changed. So in general the problems encountered in Army plant operation are somewhat different from those experienced in a municipality where the limits of design are fairly well established. They are problems, however, which may at one time or another confront any operator.

Operation difficulties in Army treatment plants, aside from design problems, have been due to several causes, virtually all of which can be grouped under the heading of "overloads." These difficulties can be outlined as follows:

A. Hydraulic:
   1. Population in excess of design conditions.
   2. High water consumption per capita.
   3. Extreme fluctuation in flow during periods of troop movement.

B. Organic:
   1. Population in excess of design conditions in conjunction with low water consumption per capita.
   2. Extreme density of population resulting in concentrated wastes because of the absence of infiltration and relatively short sewerage systems.
   3. High calorific food consumption resulting in high B.O.D. load per capita.
   4. Large amount of grease, causing increased B.O.D. load.

These difficulties resulted in several corrective steps being taken, as follows:

1. Installation of additional blower capacity to provide sufficient aeration for the high sewage strength.
2. Putting into practice a water conservation program at those plants having a high water consumption per capita (4).
3. Better construction and maintenance of grease traps, which has, in general, reduced the amount of grease received at the treatment plant.

These corrective measures have helped to eliminate some of the problems. The remaining ones have had to be accepted as peculiar to Army plants and operation based upon them. Of the remaining problems the principal ones are: (a) high sewage strength, (b) fluctuation in flow, (c) population in excess of design. Figure 1 shows the relation of the

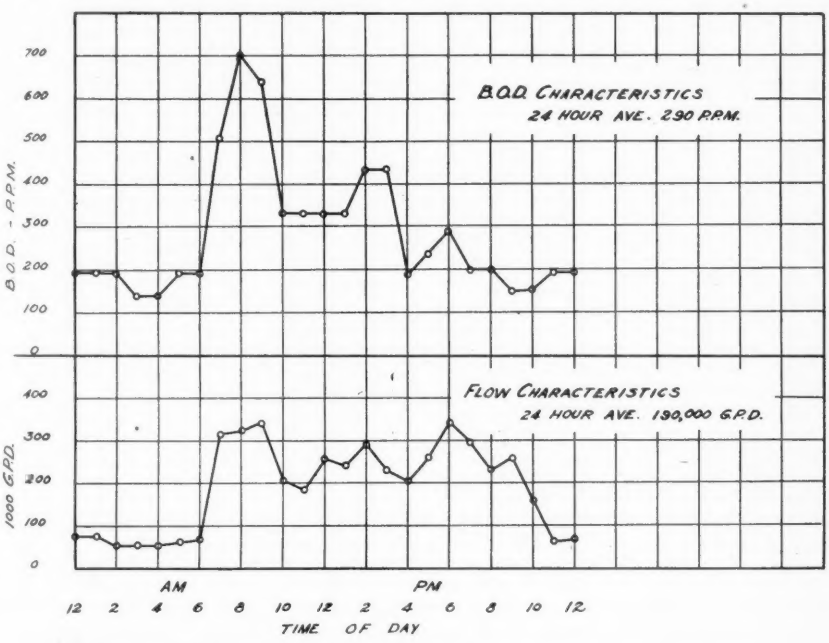

FIGURE 1.—B.O.D. and flow characteristics of raw sewage at one Army camp.

hourly fluctuation in flow to the B.O.D. load at one camp. The B.O.D. data for this curve were obtained by compositing samples at half-hour intervals for two-hour periods throughout the 24 hours. The conditions prevailing at this camp are typical of all those where initial operation was supervised by the author, in that the peak flows carry the peak B.O.D. load and that 80 per cent of the total flow occurs between the hours of 6 A.M. and 10 P.M.

Types and Causes of Bulking

In almost all activated sludge plants bulking has occurred at some time or another. Bulking in Army plants has been of the general types: (a) intermittent, (b) continuous. The first type is the most prevalent and is due principally to sudden changes in population with a subsequent increase or decrease in B.O.D. loading. Bulking of this type is not generally serious as it merely presents a problem of re-establishing the proper balance between mixed liquor concentration, return sludge rate and B.O.D. load. It does present a problem when troop movements are frequent; in this case balanced plant operation is difficult to maintain. With adequate design in air capacity, tank

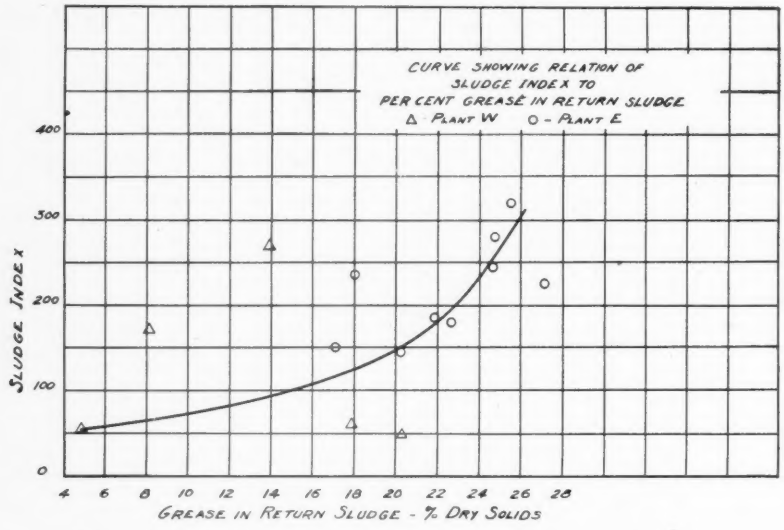
CURVE SHOWING RELATION OF
SLUDGE INDEX TO
PER CENT GREASE IN RETURN SLUDGE
△ PLANT W ○ - PLANT E
SLUDGE INDEX
0
100
200
300
400
4 6 8 10 12 14 16 18 20 22 24 26 28
GREASE IN RETURN SLUDGE - % DRY SOLIDS

Figure 2.—Relation of sludge index to per cent grease in return sludge.

size and hydraulics, however, these shock loads can be absorbed with little difficulty. The upsets, in almost all cases, are due to loadings far in excess of design. The second type of bulking has been due almost exclusively to continuous overload either in total flow or B.O.D. load. Grease has caused some trouble but experiments have shown that there is little, if any, correlation between grease content of the sludge and sludge index (Figure 2) and it is believed that grease can only be blamed in those cases where there is an excessive rise in the B.O.D. load due to it. Bulked sludge at Army camps has exhibited the same general characteristics as those reported by previous investigators. It contains a large amount of fungus and is low in biological activity.

Figure 2 was obtained by running grease analyses on composite samples of the return sludge at two plants, E and W. The analyses were determined with chloroform as the solvent and extracting in a

soxhlet for 4 hours. It can be seen that there is difficulty in drawing a curve between these points and even the one drawn shows comparatively little increase in sludge index for a large increase in per cent grease. Also several points not shown on the graph, at indices above 500, show no relation whatever to the curve drawn. It has, therefore, been concluded that grease has little, if any, bearing on the sludge index.

Operation Experiences Using Chlorine to Control the Sludge Index

The three plants at which chlorination was practiced to control the sludge index are located at widely separated points. One is located on the northeast Atlantic Coast, the second is in the Southeast and the third in the Midwest. A distance of more than 800 miles separates each from the other yet the bulking sludge in each revealed the same characteristics. The eastern plant (E) had trouble due to hydraulic and organic overload from the day it was put in operation. The southern plant (S) operated satisfactorily for a while but then developed periodic bulking troubles due to low flow and long detention periods. The western plant (W) operated very well for several months after starting but then developed bulking due to overload. All three plants are small but are typical installations for the small camps.

Table 2.—*Location, Type and Capacities of Plants Studied*

Plant	Design Flow (M.g.d.)	Type	Location
S	0.500	Diff. Air	Southeast
E	0.700	Diff. Air	Northeast
W–1	0.330	Diff. Air	Midwest
W–2	0.330	Diff. Air	Midwest

Plant E

Chlorine was first used at Plant E in an attempt to control the sludge index, which at that time was averaging approximately 300. While this index is relatively high the sludge did not exhibit many of the characteristics of a bulked sludge. It was desired, however, to obtain better settling because of the high daytime rate of flow which averaged more than 50 per cent over the design flow although the 24-hour average was only 0.150 m.g.d. over design. During the high flow it was impossible to keep the blanket in the final tanks low enough to prevent floc from going over the weirs. Chlorine was introduced in the return sludge at a point which allowed 2 to 3 minutes contact period. The initial dose was 6.0 p.p.m., based on the return sludge rate, or 0.34 per cent chlorine based on the dry solids in the return sludge. After a week's trial, chlorination was discontinued as the effluent became very turbid and the index was not improved. Two months later bulking became really violent, the sludge index reached 1,100 and chlorination was tried again. This time it was applied in the aeration effluent in

the discharge channel just prior to the entrance to the final tanks. An immediate improvement in index was obtained, as shown in Figure 3. An experiment was then conducted to determine the best point of application of the chlorine. After six days of application in the aeration effluent the dosing point was changed to the return sludge where it was applied for eight days. During this period the sludge index was stable

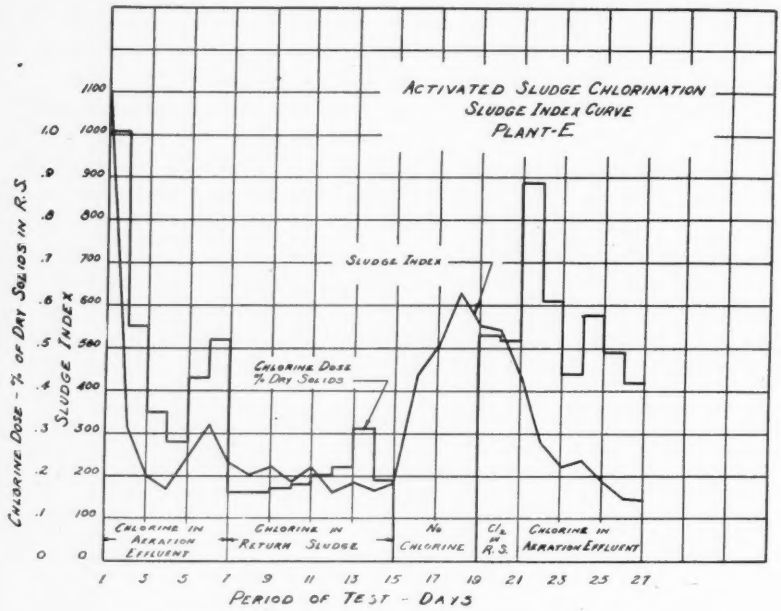

FIGURE 3.—Effect of chlorination on sludge index at Plant E.

at 200. Chlorination was then stopped. The sludge index immediately began to rise and within three days was up to 640. Chlorination was resumed, applying it first in the return sludge and then in the aeration effluent; the index was again lowered. Analyses of Figure 3 show:

(1) Chlorine applied to the activated sludge resulted in an improved sludge index.
(2) Improvement in sludge index was accomplished whether chlorine was applied in the return sludge or in the aeration effluent with more rapid improvement at the latter point of application.
(3) Approximately twice as much chlorine was needed to lower the index when the chlorine was applied in the aeration effluent.

Table 3 gives a further analysis of Figure 3, comparing the chlorine dosage in p.p.m. of the total flow to the dosage in per cent of dry solids in the return sludge (averages for the period of the test):

TABLE 3.—*Chlorine Application in Plant E*

Period (Days)	Point of Application	Cl_2, P.p.m. Total Flow		Cl_2, Per Cent Dry Solids	
6	Aer. Eff.	3.3		0.53	
8	Ret. Sludge	2.3	Ave. 2.5	0.20	Ave. 0.26
2	Ret. Sludge	3.2		0.52	
6	Aer. Eff.	4.7		0.56	

With these results chlorination of the return sludge was introduced as an integral part of operation. The improvement rendered by it did not solve the problem entirely but it did improve overall operation and made it possible for an overloaded plant to produce a much better effluent (Table 4).

TABLE 4.—*Operation Data, Plant E (Design Flow 0.7 M.g.d.)*

Period	Flow (M.g.d.)	B.O.D.				Susp. Solids				Sludge Index	Remarks
		Raw (P.p.m.)	Pri. (P.p.m.)	Fin. (P.p.m.)	Per Cent Red.	Raw (P.p.m.)	Pri. (P.p.m.)	Fin. (P.p.m.)	Per Cent Red.		
Oct.–Dec., 1941, incl.	0.812	231	201	46	80	237	141	90	63	668	Prior to Chlorination
Jan., 1942	0.825	300	225	30	90	250	140	36	86	200	After Chlorination

PLANT S

This plant was one of the first of the Army activated sludge plants to be constructed. It was built in record time and put into operation, literally, "before the roof was on the control house." Initially the flow was well under the design limit but operation was difficult due to septic conditions in the oversize final clarifier. Also, the lack of laboratory equipment precluded adequate control. The plant at this time was subject to periodic bulking and, while it produced a good effluent between these periods, the overall results left much to be desired. Many experiments were performed in an attempt to control bulking but none was successful. Following the work at Plant E, chlorination of the return sludge was started. This proved of immediate aid, reducing the sludge index from over 900 to 150 in two weeks (Figure 4). The chlorine was applied in the return sludge at a point which allowed approximately 3 minutes contact period. The initial dose was 0.48 per cent of the dry solids in the return sludge and was gradually lowered to 0.19 per cent with a stable index of 120 being maintained by applying 0.23 per cent. No regular microscopic analyses of the sludge were made.

The initial reaction resulting from the application of the chlorine, other than the lowering of the sludge index, was an increase in the turbidity of the final effluent. This turbidity did not disappear until the mixed liquor concentration was built up to 1,200 p.p.m. At the start of chlorination the mixed liquor concentration was 600 p.p.m. This reaction meant, in effect, that a clear effluent was not obtained until the chlorine dosage was decreased to 0.33 per cent of the dry solids in the return sludge. At this time the two curves as plotted in Figure 4 coincided. Actually the dosage on a p.p.m. basis was kept constant but

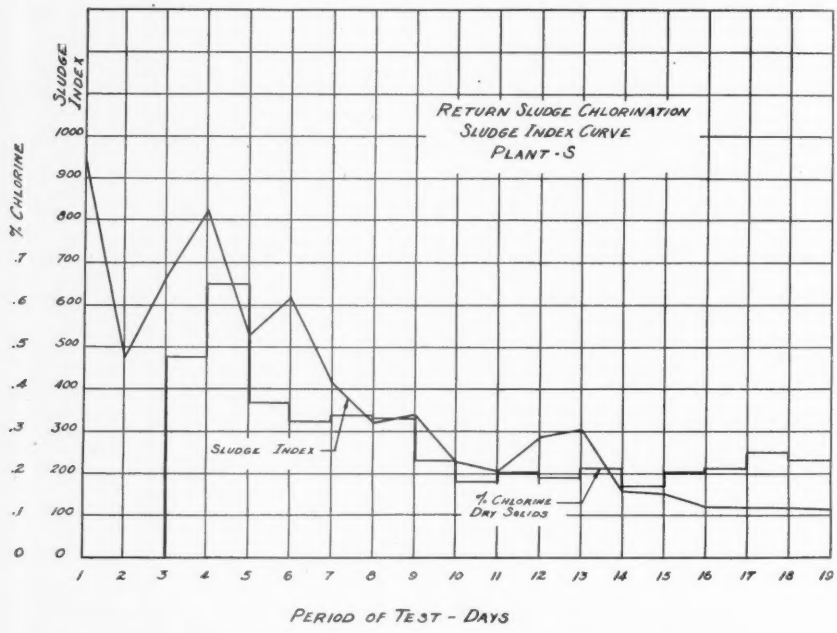

FIGURE 4.—Effect of chlorination on sludge index at Plant S. First test.

as the concentration of solids in the return sludge increased the chlorine dosage on a percentage basis decreased. Within certain limits then, it appears that microscopic examination for the purpose of control of chlorination is not necessary, as adjustment to the proper dose can be made through control of the return sludge concentration based on visual observation of the final effluent. These limits, from the author's experience, are fairly broad as dosages from 0.9 to 0.15 per cent have been used without ill effect. That is, the turbidity which resulted in the case of the higher dosages was eliminated in a few days by either increasing the return sludge concentration or decreasing the chlorine dosage.

Pursuant to the results obtained by these experiments, chlorination of the return sludge was instituted as a regular procedure and has been practiced ever since, enabling this plant to produce an excellent effluent.

Table 5 shows a comparison of the laboratory analyses before and after chlorination was used. Regular B.O.D. determinations were not run prior to chlorination as no incubator was available.

TABLE 5.—*Operation Data, Plant S (Design Flow 0.5 M.g.d.)*

Period	Flow (M.g.d.)	B.O.D.				Susp. Solids				Sludge Index	Remarks
		Raw (P.p.m.)	Pri. (P.p.m.)	Fin. (P.p.m.)	Per Cent Red.	Raw (P.p.m.)	Pri. (P.p.m.)	Fin. (P.p.m.)	Per Cent Red.		
Sept.–Dec., 1941, incl.	0.315**	318*	189*	51*	84*	145	110	33	77	993	Prior to Chlorination
Feb.–July, 1942, incl.	0.612	319	225	15	95	203	—	14	93	242	After Chlorination

** Three months data.

* Average of 12 B.O.D.'s, only analyses run during this period due to the lack of an incubator at the plant.

All other data are averages of daily analyses.

Approximately a year after chlorination was started as a regular practice an experiment was performed to check the effect of the chlorination. The chlorine dosing was stopped and the sludge index allowed to increase until the sludge blanket was at weir level in the final clarifier. This took seven days and occurred at an index of 670 whereas the ordinary operating index was 200. Chlorination was then resumed

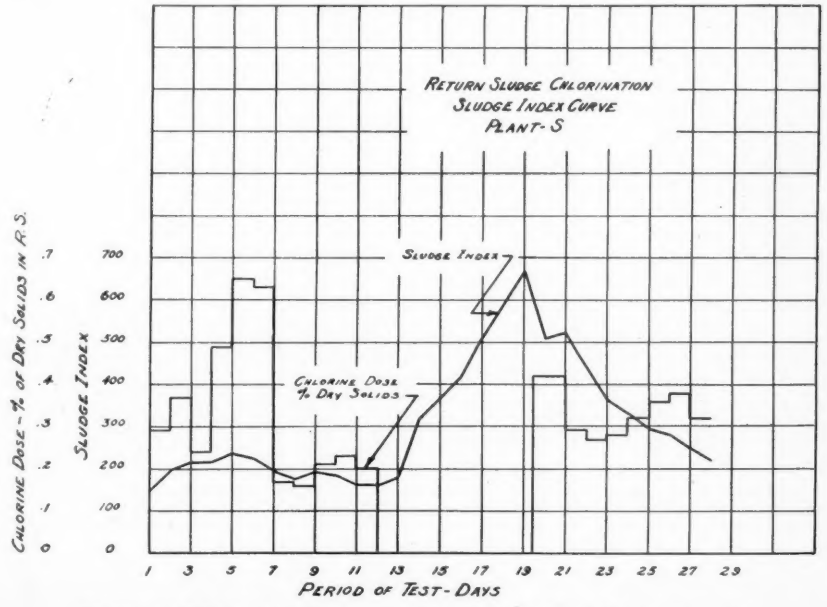

FIGURE 5.—Effect of chlorination on sludge index at Plant S. Second test.

and within nine days the index was back to normal (Figure 5). A more rapid improvement in index could have been obtained by an increased chlorine dose, but this would have resulted in a turbid effluent.

Table 6 gives a tabulation of the data from which the curve in Figure 5 was drawn. Examination of the suspended solids data on the mixed liquor shows that the average weight of suspended solids during the two periods of chlorination was 666 p.p.m. while during the period

TABLE 6.—*Return Sludge Chlorination at Plant S, March, 1943*

Date	Suspended Solids		Sludge Index	R.S. Rate 1000 Gal. per Day	Lb. Cl_2 per Day in R.S.	Cl_2—P.p.m. in R.S.	Per Cent Cl_2 of Dry Sol. in R.S.
	M.L.	R.S.					
4	341	3516	147	125	10	9.6	0.29
5	674	2578	193	125	10	9.6	0.37
6	836	4084	215	125	10	9.6	0.24
7	561	2766	214	125	14	13.4	0.49
8	302	2502	232	125	17	16.3	0.65
9	401	1528	224	125	10	9.6	0.63
10	675	4622	193	150	10	8.0	0.17
11	906	5132	176	150	10	8.0	0.16
12	988	4570	192	125	10	9.6	0.21
13	758	4124	185	125	10	9.6	0.23
14	674	4064	163	150	10	8.0	0.20
15	572	3260	157	150	0	0	0
16	562	3172	178	175	0	0	0
17	818	3646	318	175	0	0	0
18	682	3558	367	150	0	0	0
19	698	2760	415	175	0	0	0
20	524	2748	515	175	0	0	0
21	611	2964	589	175	0	0	0
22	672	3036	674	150	0	0	0
23	422	1960	509	175	12	8.2	0.42
24	688	3044	523	175	13	8.9	0.29
25	820	3360	439	175	13	8.9	0.27
26	756	3200	357	175	13	8.9	0.28
27	702	2832	328	175	13	12.5	0.32
28	742	2906	296	150	13	10.4	0.36
29	638	2760	282	150	13	10.4	0.38
30	762	3248	249	150	13	10.4	0.32
31	679	3251	221	150	13	10.4	0.32

when no chlorine was applied the solids were 642 p.p.m. This indicates that the rise in index was not due to a decrease in solids or conversely that the lowering of index was not due to an increase in solids. The average rate of return sludge during this period was 25 per cent of the flow.

Data for a year show that the average chlorine dosage applied at Plant S is 0.33 per cent of the dry solids in the return sludge, which is the figure at which best results were obtained in the first experiment. With this dosage the index was held at an average of 246. With the aid of the chlorine this plant was also able to take monthly overloads up to 160 per cent of design without impairing the quality of the effluent.

Plant W

The sewage treatment facilities at Plant W are peculiar for they consist of two separate and identical plants located side by side. This unusual situation was brought about by an increase in design population and it was considered more economical to build two plants than to enlarge the first. Each plant is designed to treat 0.33 m.g.d. or a total of 0.66 m.g.d.

The first plant to be put in operation functioned very well for four months (B.O.D. reduction 93 per cent) during which time the flow gradually increased until it was 88 per cent of design. The second plant was then put in operation because (a) the daytime (16-hour) average flow of 0.4 to 0.5 m.g.d. proved too much for the one plant to handle and (b) the B.O.D. of the raw sewage rose from the four-month average of 253 p.p.m. to 458 p.p.m. The increased load had brought on a typical case of chronic bulking in the first plant before the second plant was put in service. The decreased load resulting from the addition of the second plant, however, did not bring about the expected recovery in the first. Chlorination of the return sludge was then tried in the first plant and an immediate improvement in operation resulted. Having noted the improvement rendered by chlorination it was decided to use the second plant experimentally and to collect more data on chlorination, meanwhile taking most of the flow through the first plant, in which chlorination was continued.

Half of the second plant was used for the experiment, so the flow introduced was set at one-quarter of the total to give identical flow conditions in both plants. One variable existed, however, for it was not possible to reduce the rate of return sludge in the experimental plant to the same proportion of the flow as that used in the first plant. The laboratory analyses made were the same as in all previous work with these additional determinations:

(1) Chloroform soluble material in the raw sewage.*
(2) Chloroform soluble material in the return sludge, per cent of dry weight.*
(3) Chlorine demand of the return sludge.
(4) Per cent of chlorine demand satisfied.

At the start of the experiment the sludge was badly bulked (sludge index 1,400) but the bulking was helped along intentionally as the worst possible conditions were desired. Collection of data was begun five days prior to the start of chlorination by which time the sludge was very light, diffuse in floc structure and contained very little fungi. The solids in the mixed liquor were very low (300 p.p.m.) and the sludge settled to only 66 per cent in 30 minutes. Chlorination was then begun with an initial dose of 2.3 per cent of the dry solids in the return sludge and was applied in the return sludge trough at a point which allowed 3 minutes contact period. This initial dose was extremely high due to

* Analyses were made on 24-hr. composite samples, using 4-hr. extractions.

the inability of measuring very small dosages with the chlorinator on hand. The reaction was as expected as the sludge index was immediately lowered and the effluent became turbid. Turbidity was more pronounced in this case than in those previously reported for the chlorine dose was much larger than necessary, however, the floc was not broken up but compacted well. Chlorination was continued for eight days, by which time the index had been brought down to 60. The experiment was then concluded as it had definitely shown that even large doses of chlorine could be used to settle a bulked sludge without causing irreparable damage to the sludge floc. Also, sufficient other data were collected to draw conclusions. Analyses of the chlorine demand before and after chlorine was applied were run several times daily but proved so variable and subject to error that this test was discarded as a worthless control.

The conclusions drawn from this experiment were:

(1) Grease in the raw sewage had no effect on or correlation with the sludge index.

(2) High dosages of chlorine applied to a light diffuse floc result in an improvement in sludge index but cause an increased turbidity in the effluent. This turbidity can be eliminated by increasing the concentration of solids in the return sludge, which in effect reduces the chlorine dosage applied.

Results of this experiment are shown in Figure 6.

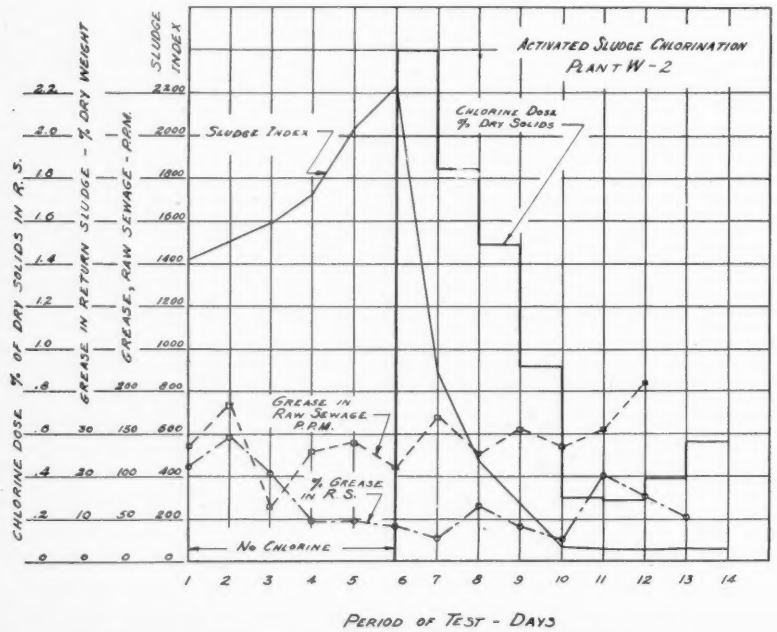
ACTIVATED SLUDGE CHLORINATION
PLANT W-2
SLUDGE INDEX
CHLORINE DOSE % DRY SOLIDS
GREASE IN RAW SEWAGE P.P.M.
% GREASE IN R.S.
NO CHLORINE
CHLORINE DOSE % OF DRY SOLIDS IN R.S.
GREASE IN RETURN SLUDGE - % DRY WEIGHT
GREASE, RAW SEWAGE - P.P.M.
SLUDGE INDEX
PERIOD OF TEST - DAYS

FIGURE 6.—Effect of chlorination on sludge index at Plant W-2.

During the period of experimentation with the second plant, chlorination was continued in the first until the sludge index was down to 85. Chlorination was then stopped and the index immediately went up again (Figure 7). Chlorination was then resumed. The sludge index was again reduced although it took four days before any appreciable change was apparent. A few days later however, the index was again down to 85. For 19 days, while the chlorination study was being carried on at the first plant, determination of the volatile solids in the return sludge was made. These results, also shown in Figure 7, revealed

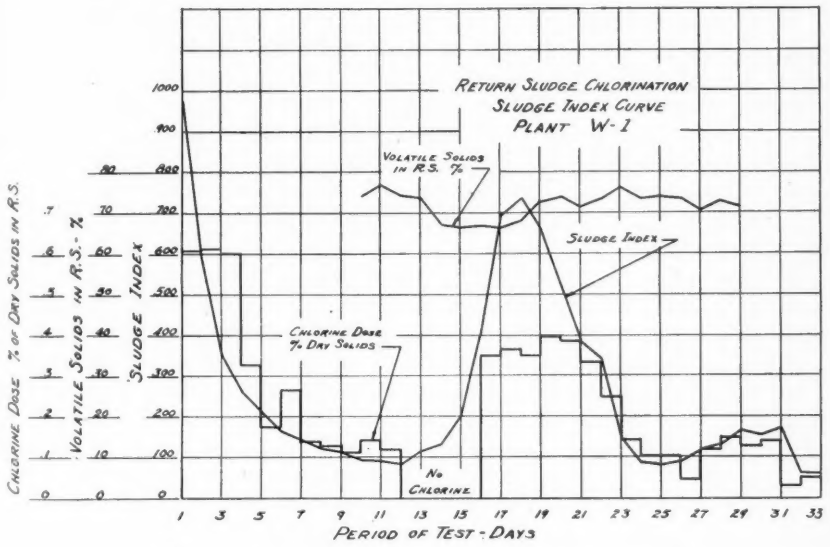

FIGURE 7.—Effect of chlorination on sludge index at Plant W-1.

that the variation in the volatile content had little relation to the sludge index, thus substantiating the fact that the chlorine alone was responsible for the reduction in index. During the periods when the index was lowest the volatile content of the sludge was fairly stable; during the period following the stopping of the chlorine the volatile solids dropped, indicating a reduction in sludge activity. Ordinarily, a low volatile content is associated with a good settling sludge yet in this case the index rose when the volatile content dropped. However, it is not known whether or not this phenomenon holds true in all cases where chlorine has been applied for control of the index, as sufficient data were not collected on each experiment to draw any definite conclusions.

Examination of Figures 4 and 7 show a very interesting relationship between the percentage of chlorine applied and the sludge index as plotted. The areas enclosed by the sludge index curve and the chlorine dosage curve are almost equal. This suggests the existence of a mathematical relationship between the two which would serve as a basis for

determining the dosage of chlorine to apply to a bulked sludge. This relationship can be expressed as:

S.I./1,000 = Per cent Cl_2 dosage in return sludge, or
S.I. × F × W × 0.0000834 = Pounds of Cl_2 per day, where
S.I. = Sludge Index (Mohlman),
F = Return sludge rate in m.g.d.,
W = Suspended solids in return sludge in p.p.m.

Theory of Chlorination for Sludge Index Control

To date it has not been possible to determine definitely the exact function of the chlorine when applied to activated sludge. It is believed that the principal benefit derived from chlorination of return sludge is a restoration of the balance between the organic load and the biological life present in the sludge needed to treat the load. Loss of this balanced condition is the cause of the sludge becoming upset and results in an increase in sludge index. When a controlled dosage of chlorine is applied, a certain portion of the biological life is killed by the chlorine with a resultant improvement in general sludge character. It is open to question whether the improvement is due to prolific regeneration of biological life at which time the demand for food is greatest; whether the chlorine kills a specific type of organism, thus creating a new and more desirable environment; or whether a definite permanent decrease in sludge activity is caused by the sterilizing action of the chlorine.

Haseltine has stated (5) that: "The primary cause of sludge bulking is a lag in biological oxidation behind adsorption. The control of bulking lies in either speeding up biological activity or providing more time for it to progress before re-introducing the sludge into the sewage." It is very possible that the chlorine, by reducing the number of active organisms which in turn causes increased activity, serves as a control of the rate of biological oxidation.

Results and Conclusions

Chlorine was applied in both the return sludge and aeration effluent at Plant E. It was found that either point of application resulted in an improved index but that application in the return sludge gave comparable results using half the amount of chlorine needed when application was in the aeration effluent.

At Plant S chlorination of the return sludge reduced the index from 993 to 242 and improved overall operation, allowing an overloaded plant to produce an effluent of 14 p.p.m. B.O.D. with an average reduction of 95 per cent.

At Plant W-1 chlorine was applied to the return sludge in amounts ranging from 13 to 48 per cent of the demand (average 24 per cent) or on a dry solids basis, between 0.05 and 0.61 per cent (average 0.24 per cent). Best reaction in sludge index improvement was obtained when

the chlorine dose was fitted to the sludge index and based upon the amount of dry solids in the return sludge. Little reliance could be placed upon the chlorine demand determinations as the results proved too variable to use as a control. When lower dosages of chlorine were used the reaction was favorable but took several days longer to become effective.

In every experiment discontinuation of chlorination resulted in bulking as before.

Grease in the return sludge, on a dry solids basis, varied from 4.8 to 29.9 per cent but did not show any relation to the sludge index, neither did it show any decrease as chlorination continued.

It was found possible to settle even a light diffuse floc with chlorine without causing damage to the floc.

It was found that the chlorine dose needed to control bulking adequately is a function of the sludge index and the dry solids in the return sludge. This relationship can be expressed as:

$$S.I. \times F \times W \times 0.0000834 = \text{Pounds of } Cl_2 \text{ per day, where}$$

S.I. = Sludge Index (Mohlman),
F = Return sludge rate in m.g.d.,
W = Suspended solids in return sludge in p.p.m.

Considering the results obtained it has been concluded: (a) that chlorination of activated sludge for the purpose of controlling bulking can be used to advantage in Army activated sludge sewage treatment plants, (b) that the best point of application of the chlorine is in the return sludge at a point which will allow 2 to 3 minutes contact period and (c) that the proper dosage of chlorine is a function of the sludge index and the dry weight of solids in the return sludge.

Although this paper has been primarily concerned with the original work done at Army treatment plants, the principles determined as to dosage of chlorine required have since been employed at several other plants treating municipal sewage. The results in almost all cases have corroborated the original findings and control of the sludge index thus obtained. In some instances chlorine has been dosed on an intermittent basis but this method does not appear as successful as continuous application. When intermittent dosing is used the plant is kept in a constant state of fluctuation as the index is following a cycle. Oftentimes the total amount of chlorine needed to reduce the index when the high point of the cycle is reached is greater than if application is practiced continuously at a small dosage.

While the investigation proved satisfactorily that chlorination for the control of bulking was of distinct advantage, it is not recommended that it be considered a cure-all for all cases of bulking. The causes of the unbalancing of the sludge must be carefully analyzed to determine whether the condition is due to biological or physical reasons. If physical, the sludge condition can be improved by adjustments leading to the balancing of the concentration of mixed liquor solids, the return sludge rate and the air application for the B.O.D. loading present.

ACKNOWLEDGMENTS

The author wishes to express his thanks and appreciation for the cooperation and help of the various superintendents and operators of the Army treatment plants at which these data were collected. It is regretted that acknowledgment can not be made by name, however, this is impossible at the present time due to Army regulations.

The author is indebted to the following superintendents for the data used in Table I: Miles Lamb, Belvidere, Ill.; R. R. Johnson, Canton, Ill.; S. S. Crawford, Lake Charles, La.; D. Backmeyer, Marion, Ind.; Wm. Dillon, Byron, Ill. These data were composited from monthly reports submitted to the Chicago Pump Co., by the superintendents mentioned.

BIBLIOGRAPHY

1. Smith, Russell S., and Purdy, W. C., "Use of Chlorine for the Correction of Sludge Bulking in the Activated Sludge Process." *This Journal*, **8**, 2, 223 (March, 1936).
2. Ridenour, G. M., Henderson, C. N., and Schulhoff, H. B., "Operation Experiences with Chlorination of Activated Sludge." *This Journal*, **9**, 1, 63 (January, 1937).
3. Mohlman, F. W., "The Sludge Index." *This Journal*, **6**, 1, 119 (January, 1934).
4. Kessler, Lewis H., and Norgaard, John T., "Operation of Army Sewage Treatment Plants." *This Journal*, **14**, 6, 1228 (November, 1942).
5. Haseltine, T. R., "The Use of Hydrated Lime in the Activated Sludge Process." *This Journal*, **10**, 6, 1017 (November, 1938).

Industrial Wastes

EXPERIENCES WITH SODIUM NITRATE TREATMENT OF CANNERY WASTES *

By William A. Ryan

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The ability of nitrates to prevent odors in sewage and waste matter was studied by Clark and Gage of the Massachusetts State Board of Health many years ago. The author's first experience with practical application of the treatment was in 1923 at Boston, where Metcalf and Eddy used sodium nitrate to correct objectionable conditions caused by anaerobic decomposition of sewage and industrial wastes during warm weather and low flow of water in the Blackstone River. There was little sodium nitrate used in the sanitary field, outside of the laboratory, until 1940 when N. H. Sanborn, Chief Research Chemist of the National Canners Association, Washington, D. C., conducted field tests in three experimental lagoons. These tests were conducted at a canning plant near Rochester and it was the writer's privilege to visit this plant and to keep in close touch with the experiment. The results obtained were satisfactory in spite of the fact that strong cannery wastes, comprising the process wastes from the pea pack, ensilage juice from the stack, cow barn and dairy waste, were all pumped to the lagoon.

During the past four years additional experiments, both on pilot plant and plant scale bases, have been continued by Sanborn, Black, Warrick and Halvorson. Sodium nitrate treatment is now an established method of treatment in the Middle West where large plants pack corn as the major item.

The usual procedure in treating corn waste is to screen and pump the screened effluent to a large lagoon. The sodium nitrate is added to the waste in the pump sump following the screen.

The unit established for reporting a canning plant pack is the case of No. 2 cans, which consists of twenty-four 20-oz. cans. It was first suggested to add sufficient sodium nitrate to satisfy 50 per cent of the 5-day B.O.D. of the screened waste. This was decreased to 40 per cent and in some cases to 20 per cent. It has now been suggested to add 150 lb. of commercial sodium nitrate (16 per cent nitrogen) to the waste from 1,000 cases of No. 2 cans. This is an arbitrary standard but is easy to follow.

After the waste enters the holding lagoon the anaerobic bacteria present in the waste, plus additional soil bacteria consisting of miscellaneous anaerobes, aerobes and faculative organisms, begin to break

* Presented at meeting of the Genessee Valley Section, New York State Sewage Works Assn., held at Lyons, N. Y., on May 5, 1945.

down the organic matter. As soon as the dissolved oxygen has been depleted, the bacteria make use of the oxygen in the nitrates. This oxygen, when released, is in the nascent or atomic state and is more active than the molecular oxygen of the air. The process continues until all available nitrate oxygen has been consumed. If insufficient nitrate oxygen is present the biochemical action continues until the sulfates are robbed of their oxygen and hydrogen sulfide odors develop.

One practice in the Corn Belt is to discharge a certain portion of the waste to a recirculating filter and pump the filter effluent back to the lagoon. In this manner additional nitrates are formed biologically in the filters from the ammonia produced by the reduction of the nitrates in the lagoon. It is a problem in economics whether to add sufficient nitrate to the waste leaving the canning plant to satisfy the oxygen demand or to recirculate through filters or aerators, and thus produce additional nitrate. Unlike sewage, cannery wastes are unbalanced in relation to protein and fat content and consist chiefly of carbohydrates (starches and sugars), cellulose and small amounts of proteins and fats. It is likewise lower in bacteria, both as to types and numbers.

Treatment of Pea Wastes

A full scale experiment was conducted during the summer of 1944 at the plant of the Comstock Canning Corporation in Red Creek, N. Y., on pea waste. The waste treatment plant consists of a rotary screen covered with 40-mesh screen cloth, a settling tank approximately 40 by 10 by 8 ft. which serves as a pump sump, pump and motor and a lagoon capable of holding approximately five million gallons.

There is a viner station near the plant, but a large percentage of the peas processed at this plant are threshed at nearby viner stations. All the process waste, blancher water and wash water—approximately 20 gallons per case—plus the ensilage juice from the pea vine stack, was pumped to the lagoon. Cooling tank water, boiler blow down water and retort water were discharged directly to the nearby stream.

Ten tons of sodium nitrate were added in solution to the lagoon during the month of July. No consideration was given to the extra B.O.D. load occasioned by the addition of the stack juice. Sodium nitrate is readily soluble, as 87.7 parts will dissolve in 100 parts of cold water. The nitrate was added to the tank following the fine screen and delivered to the lagoon with the screened waste liquor. It is usually advisable to add the calculated amount for the total pack during the first three weeks of the pea season, in order to encourage the growth of the nitrate splitting micro-organisms and thereby obtain protection against the formation of odor producing compounds.

The experiment was conducted under the supervision of the cannery superintendent and the samples of lagoon liquid were collected and

analyzed by the writer. Results of analyses of the wastes entering the lagoons were as follows:

	Pea Waste	Ensilage Juice
5-Day B.O.D., p.p.m.	1500	51,000
Oxygen consumed (30-min.), p.p.m.	1280	—
pH	6.2	4.4
Total solids, p.p.m.	—	55,700

A 20-day B.O.D. was determined on the pea waste and the demand increased to 1,700 p.p.m., indicating that pea waste has an immediate rather than a delayed demand for oxygen. The first peas were processed on July 12 and the first sample was collected for analysis on July 31.

Results of analytical and other observations at the lagoon are summarized in Table I.

TABLE I.—*Lagoon Data. Pea Cannery Wastes Treated with Sodium Nitrate*

Date (1944)	July 31	Aug. 10	Sept. 2	Oct. 16	Oct. 27	Dec. 12
Color	Black	Black	L. Brown	L. Brown	L. Brown	Green
Ammonia nitrogen, p.p.m.	120	120	60	—	—	8
Nitrate nitrogen, p.p.m.	100	30	0.5	—	—	—
5-Day B.O.D., p.p.m.	750	1440	210	93	57	0
Alkalinity as $CaCO_3$, p.p.m.	930	1140	—	—	—	—
Chlorides, p.p.m.	870	790	—	—	—	—
Total solids, p.p.m.	2962	3789	—	—	—	—
pH	7.0	7.0	7.2	7.3	—	9.1
Total bacteria	—	20,000	—	—	—	—
Odor	Slight	Trace	None	None	None	None
D.O., p.p.m.	—	—	—	—	—	17.6
Oxygen consumed, p.p.m.	—	—	—	—	—	42
Algae	—	—	—	—	—	Present

The sodium nitrate started to be reduced to ammonia and to give up its oxygen a few days after the waste was added. The low initial B.O.D. of the lagoon contents was due in part to the presence of rain water runoff in the lagoon before starting the test. The increase in B.O.D. in the sample collected on August 10 showed the influence of ensilage juice. This also accounts for the increase in total solids. While the ensilage stack may not deliver more than one g.p.m. of juice at the start it will increase, as fermentation develops, to three or even five g.p.m., depending on the size of the stack. The pH increased slowly and the water remained dark in color until late fall. The agar count was not high and many of the colonies appeared to be similar in appearance.

Many persons residing within a half-mile radius of the lagoon were interviewed and they all stated that the odor was greatly reduced as compared with previous years.

Discussion

It is difficult to evaluate properly all factors contributing to the purification of wastes in a lagoon. It is believed advisable to keep depths under four feet in order to secure greater benefit from wind action, which causes motion of the water, and to obtain better penetration of sunlight to encourage algae growth and increase the temperature of the liquid. It is good practice, where lagoons are used in the disposal of waste, to select a suitable location in order that the treated effluent may be discharged into nearby streams at times of high water.

It is the writer's opinion that better results can be obtained with the use of sodium nitrate if the sanitary sewage or effluent from the septic tanks at the canning plant are allowed to discharge into the lagoon with the plant wastes so as to stimulate bacterial growth by seeding. This is particularly true in the case of potato, beet, or carrot wastes from plants using caustic soda in the peeling process, because such wastes are almost sterile. A laboratory test conducted by the writer on a lye peel beet waste revealed that sewage addition was required to simulate lagoon conditions where soil bacteria are present.

If pea stack juice is allowed to enter the lagoon with process wastes, additional sodium nitrate must be added.

Sodium nitrate is classified as a critical material at the present time. It will be plentiful following the war, however, and will be reasonable in price. Its application may be advantageous for the control of odors from septic sewage or industrial wastes if the proper bacteria are present and if storage is for two weeks or longer.

Sodium nitrate contains 56.4 pounds of available oxygen in every 100 pounds and in addition yields 19.3 pounds of ammonia through reduction of the nitrate. The ammonia is useful in control of pH and in holding volatile compounds in solution. The ammonia also neutralizes the organic acids present in vegetable and fruit wastes.

Reference

N. H. Sanborn, "Use of Sodium Nitrate in Waste Treatment." *Canning Trade*, March, 1941.

Construction

BETTER SEWERS

By Benjamin Eisner

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Of all the fields of engineering which have become more or less standardized through long experience, construction and installation of sewers is still among the leaders in percentage of substandard finished work. Perhaps this is the result of too much familiarity and consequent contempt for careful control. Perhaps it is due to a common but unfounded belief that such work is essentially simple. More than likely it is due to a pronounced decline of respect on the part of both the public and the engineer. Wartime emergency construction has emphasized as well as added to the general lowering of quality standards.

The need for speed and the lack of adequate equipment, sufficient and experienced labor, satisfactory materials and, especially, a lack of adequate inspection, do not explain away the very apparent neglect of quality nor the pride of workmanship which at one time characterized sewerage engineering. There seems to be a growing tendency among architectural planners of large scale residential developments to avoid the employment of consultants for sewerage and drainage planning. Designers of industrial expansions divert sewerage and drainage design from consulting engineers to their piping draftsmen. In such groups the sewerage and drainage system is coming to be considered as a mere extension of the interior plumbing system.

To the typical licensed plumber a sanitary engineer is one expert in plumbing layout and equipment. Many architects do not differentiate between interior and exterior pipe work. The consulting sanitary engineer has not invaded the field of interior piping but circumstances have forced the plumbing and heating craftsman into the field of sewerage work.

In spite of all the recommendations to the contrary, municipalities persist in selecting consultants on competitive price bidding. Quite obviously there can be no equitable basis of comparing the caliber of service to be obtained from the various bidders and, ultimately, award of a contract for engineering service on a lowest price basis brings about degradation of quality in finished construction. An unwholesome offshoot of competitive bidding for engineering service is the now common division of such work into parts; preparation of preliminary reports, preparation of detail plans and specifications, and supervision of the progress of construction. It is not at all uncommon to find three separate agencies employed, one on each such part of the project. This

sort of split may produce small savings in cost of engineering but not necessarily a similar saving in total cost. The result is much more apt to be substandard work.

Still another step backward results from political rather than technical control of inspection. So long as appointment as an inspector of sewer construction is the reward of faithful political service, just so long will there be either excessive inspection cost or, what is more probable, deficient inspection and materially deficient construction quality.

The consulting engineer on sewer work who fails to keep abreast of current improvements and developments in his field is not entirely free from a part, at least, of the responsibility for declining construction standards. Sometimes, not frequently but often enough to be disturbing, the gap between intended and attained result, due entirely to the use of obsolescent methods and materials, is serious.

As the quality of sewer work goes down, the respect for engineering services goes down with it, and the engineer finds it increasingly difficult to obtain adequate compensation for his work. The competent and incompetent suffer alike. The public comes to hold so little respect for his work that in municipal budgets, sewer appropriations are the most difficult to pass and the easiest to slash. Quite naturally, the end point will be complete independence from consulting engineers unless confidence is restored.

During the course of his employment by an association of materials manufacturers, the writer has had the opportunity, usually withheld from consultants in private practice, to become intimately familiar with sewer work designed and supervised by many agencies in many parts of the country, with and without the benefit of consulting engineers' advice. At his conventions, the consultant has frequent opportunity to inspect examples of commendable engineering but he is rarely invited to examples of those that went wrong. In the hope of adding experience, vicarious of course, a few "horrible examples" are cited.

On a war emergency plant expansion including over half a mile of sewer pipe, mostly 30-inch diameter, no consultant was retained. Plans and specifications merely stipulated installation of a sewer in working order to the elevations shown on the plans. The specifications also stipulated the use of first quality materials. Although a portion of the line had collapsed, the remainder was being installed in precisely the same way as the portion which had failed. The invert elevations were approximately 24 feet below surface grade. Trenches were excavated by drag-line, producing a width of about six feet at the bottom of the trench and about 15 feet at the top. All backfilling was placed by bulldozer. Although bell holes were prepared, no special pains were taken to dress the bottom of the trench for bedding the pipe. The damage was estimated at $30,000.

Another case: An 18-inch diameter line, 4,000 feet in length, leaked so badly at the joints that the line was abandoned before it was put into use. Investigation disclosed the joints to have been well made and the

pipe in good condition. Failure was due to a pronounced settlement of the line resulting from the shifting of the soil foundation.

Another: Visual inspection of a line built in an area subject to high ground water table showed imperfectly filled joints, yet accurate weir measurements of infiltration rates were surprisingly low. Subsequently, the location of a well concealed by-pass tap into the sewer was discovered.

No building codes regulate the structural design or building of sewers. Collapses are most usually caused by complete lack of advance comparison between loads and resisting strengths. No advantage is taken of the fact that sewer pipe is available in several strength classifications, or that its supporting strength can be increased or decreased by the manner of bedding it in the trench. Insufficient attention is paid to the fact that trench loads mount rapidly with increasing trench widths.

Too many engineers and inspectors pin their faith to the integrity of the workman. Too many rely for safety on the skill of the foreman or superintendent. Competent consultants do not shrink from their responsibilities over every detail of construction, but practically all, competent and incompetent alike, are shirking their responsibility for educating the public to the need for their services.

Engineering advertisement is modest in the extreme. Such advertising cannot be expected to bring about employment of an engineer on a sewer project where none is contemplated. A better solution than advertising is necessary.

It might be advisable for each engineer who is proud of the quality of his work to volunteer educational talks and discussions at service clubs and taxpayer groups, to address meetings of architects and mechanical engineers and even contractor's organizations. It might be beneficial to enact licensing of inspectors on public work. Or, on sewer construction, it might be well that health boards now responsible for the approval of sewer plans, be equally responsible for their final acceptance. There may be other and better solutions, but in any event, the consultant on sewer work must bring his light from under the figurative bushel if he is to see sewer work quality return to pre-war standards.

THE OPERATOR'S CORNER

AN INTRODUCTION TO PUBLIC RELATIONS

Mark Twain's classic observation on the weather, that "Everybody talks about it but nobody does anything about it," is equally expressive of the public relations situation in the sewage works field. All are in wholehearted agreement that good public relations are of primary importance but that too little attention is usually given such activities in the average municipal sewerage or sewage treatment department. Maintenance of good public relations is not an intangible activity to be undertaken as an extra chore, it is a fundamental part of any public service and it will be to the advantage of every sewage works administrator to accept it as such and to act accordingly.

Good public relations constitutes the development and retention of public good will toward the service being rendered and the personnel rendering that service. A complete localized program goes far beyond plant beautification, entertainment of visitors and newspaper publicity. We suggest the following as the basic elements of a sound and practical approach to the achievement of public understanding and appreciation of the service afforded by municipal sewage works:

1. A job well done.
2. Personalized courtesy.
3. Constructive publicity.
4. Representation and participation in civic affairs.

Each of the above cardinal points comprises a story in itself. The first one will be enlarged upon somewhat here and the remaining three will be taken up separately in editorials introducing "The Operator's Corner" of subsequent issues of THIS JOURNAL.

The very foundation of a public relations program consists of the complete and efficient accomplishment of all departmental functions. Obviously, a municipal department that is continuously engaged in side-stepping complaints is in no position to expect commendation. Where the sewage collection system is carelessly and inadequately maintained, the department will make more enemies than friends because it is not meeting its responsibilities. Likewise, the sewage treatment plant which does not accomplish the results of which it is capable because of poor operation, is not a good product for "sale" to the public. Facilities that accomplish their purpose efficiently and without undue interruption in service; buildings, structures and grounds at which neatness and cleanliness are always features and good paint and good repair denote protection of plant investment; practical but attractive landscaping and fixtures; personnel who demonstrate interest in their work and display pride in their stewardship—all these combine into the "job well done." Dollar-wise economy, of course, is also a requirement—an attribute of public service which is particularly appreciated by the tax-payer.

It is true that the average citizen may not be able to comprehend entirely the technical aspects of the facilities being operated but this does not mean that any detail of operation should be given less emphasis or should be camouflaged by "window-dressing." Attractive plant landscaping should be planned to set off the various plant structures and not to hide an exposed pile of screenings; the fish pond and flower gardens should be added attractions and not depended upon to divert attention from poor plant performance.

It is realized that inadequate and faulty service may result in some instances in spite of the best efforts of operation personnel, usually because of limited sewer system or plant capacities or because of design features. In such cases the public as well as the city officials should be informed that improved or expanded facilities are required since one of the chief purposes of a public relations program is to develop public understanding of the service—in regard to both its advantages and its shortcomings.

The well managed, efficient, and economical public service will, to a large extent, sell itself to the public. The municipal department that lays its foundation on this firm subgrade will find public good will easy of achievement.

W. H. W.

THEORY AND OPERATION OF SEPARATE SLUDGE DIGESTION UNITS*

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While our ultimate object is to solve specific individual sludge digestion problems, let us begin with an attempt to learn something of the reasons why. Why does sludge digest? Why does it *not* digest? Can we logically hope to "lift the curtain" in an endeavor to view the "behind the scenes" activity within a separate sludge digestion tank?

Let us consider first, however, the practical accomplishments of sludge digestion. They are briefly (a) reduction in volume; (b) improved ability to drain and dry, and (c) reduction or complete elimination of offensive odor.

The digestion of sludge is primarily a matter of biochemistry. Now what does that mean?

One definition would be the study of the composition of life substances and the changes of composition which they undergo. In connection with this subject, the life referred to is bacterial life. According to Hotchkiss (1) sewage contains many types of bacteria capable of producing ammonia and hydrogen sulfide from proteins. These are one of the groups of bacteria in sewage in which we are particularly interested. In general, it is the action of such bacteria and protozoa on the organic compounds that brings about the changes which take place during digestion.

Sludge is comprised of organic and inorganic constituents. The organic compounds include, under the heading of carbonaceous material—sugars, starches, cellulose, lignins, etc., and under the heading of nitrogenous material—proteins, urea, amino acids, etc. There are also of course the fats, including vegetable, animal and mineral. Also, we must not overlook the important fact that water, as the basic element of the sewage from which the sludge is derived, is of great importance together with the bacteria which the sludge contains.

The problem of sludge digestion therefore resolves itself into ascertaining and maintaining an environment which will favor and stimulate the activities of desirable bacteria, and at the same time eliminate or arrest the activities of all undesirable forms, Max Levine (6).

We are naturally interested in the power of bacterial multiplication. This is markedly affected by (a) any change in behavior of an organism in response to a stimulus, (b) the oxygen content and (c) the nature of available food supply of their environment. The bacteria function as catalysts through the agency of enzymes. Now catalysis has to do with the acceleration or retardation of a chemical reaction by a substance

* Presented at Lecture-Laboratory Course on Sewage Treatment and Disposal, sponsored by Pennsylvania Sewage Works Assn. at St. Joseph's College, Philadelphia, Pa., on May 9, 1945.

which itself undergoes no permanent chemical change, or which may be recovered when the reaction is completed.

The next logical question would be—what are enzymes? Briefly, they are complex organic substances effecting reactions which otherwise would not occur, *e.g.*, fermentation. The action of enzymes is selective, one class hydrolyzing carbohydrates, another proteins and a third class esters. A few enzymes are found in natural secretions such as digestive juices, but more often they are obtained only from the interior of cells. Although much is not known of their chemical composition, they are reported as essentially colloidal in nature. Their function is to convert insoluble substances into compounds of lower molecular weight, through the incorporation of a molecule of water, and then splitting. There are enzymes which split fats into glycerol and fatty acids, others which break down proteins and similar complex constituents into amino acids, and yet others which are associated with the hydrolysis of the complex carbohydrates into the simple sugars.

Since oxidation plays a major role in sludge digestion, we might properly inquire as to what occurs. Oxidation involves the addition of oxygen to a compound. More generally, it is any reaction which involves the loss of electrons from an atom.

According to Warburg (2), biological respiratory oxidation takes place through the catalytic transfer of molecular oxygen, which is alternately oxidized and reduced, to the substance being oxidized. Molecular oxygen is therefore the essential and active element.

Wieland (3), on the other hand, considers the phenomenon characteristic of biological oxidation to consist of the loss of hydrogen.

As pointed out by Waksman (4), "the extent of decomposition of carbohydrates by micro-organisms is found to depend not only on the nature of the organisms, but also on the nature and amount of available nitrogen. For every unit of carbon decomposed as a source of energy, a certain amount of nitrogen is assimilated, whether the latter is present in the form of protein, simple protein degradation products, or inorganic salts."

From the standpoint of anaerobic oxidation effected in the course of sludge digestion, it is particularly significant that water not only serves as a disbursing medium in which the bacteria act upon the dissolved sewage constituents, but also enters into oxidation reactions.

In this regard, Dr. H. Bach (5) in a private communication points out that in order to become decomposed, sludge particles must be totally immersed in water, allowing the bacteria an unrestricted supply of this essentially indispensable liquid; for, as he observes, the bacterial body itself consists of far more than 90 per cent of water. He further emphasized the importance of protecting the bacteria from the access of oxygen in order to insure *true* anaerobic action, his thought being that only this kind of bacterial action results in breaking up the sludge particles in their *depths*, as compared to aerobic action, which is to his mind always confined to the *surface* of particles and therefore may be

employed only in cases where undissolved suspended matters, if at all present, are in at least minute amount, and in minute particle sizes. Another point emphasized by Bach is the necessity of protecting the bacteria from the permanent influence of products formed in the course of the bacterial actions, as a refuse of the bacterial cell or as the result of splitting action of bacteria on a substance. His thought is that carbon dioxide is especially poisonous to bacteria of any kind. He points out that carbon dioxide is split away from fatty acids, with the rest of the substance becoming transformed into methane, thus accounting for the fact that sewage sludge gas may contain some 30 per cent of carbon dioxide.

From this will be observed the value and the importance of maintaining submergence of all material to be digested at all times!

Many organic substances (carbohydrates, fatty acids, proteins) are fermentable to carbon dioxide and methane, when added to an active sewage sludge seed. "Buswell, Fair and Rudolfs, with their collaborators, have differentiated the effect of environmental conditions—temperature, reaction, concentration of inorganic and organic constituents—upon the rate of methane production, but investigations on the roles of the various bacteria in such fermentation mixtures are rather meager.

"Organic acids constitute a primary end-product of decomposition of the amino acids and this is also true with reference to the first stages of decomposition of carbohydrates. If conditions in the environment preclude the further rapid oxidation of these acids, they will accumulate and interfere with the train of biological transformations." To speak more practically and less theoretically, and as pointed out also by Bach, the layer of "top sludge" at the surface of the contents of a sludge digester, partly or temporarily forming a crust penetrating into the sludge gas atmosphere, obviously is in reverse to the conditions stipulated, due to a lack of water on one side and the presence of carbonic acid poisons on the other.

Again, the action which progresses in sludge digestion is brought about through the use of the organic matter as bacterial food. The material is liquefied by secretions of the bacteria, known as enzymes. The liquid is then absorbed in the bacterial cell, where changes occur which cause the cells to grow and multiply by splitting them up into parts. Each part in turn becomes a new focus of life and eventually splits again. Optimum conditions must be provided for growth of the organisms which accomplish the decomposition as well as for the proper biological, physical and chemical environment. Numerous investigations of the favorable factors in digestion have demonstrated that control of the temperature is a more important factor than pH control.

Foaming

Injurious action due to rapid bacterial growths or excessive microbial action is associated with such phenomena as acid fermentation,

generally referred to as foaming. Acids are formed as the primary fermentation products of carbohydrates, fats and proteins. In a properly functioning digestion tank these organic acids are further broken down to carbon dioxide and methane. Where the rates of acid production in the primary stages of fermentation are greater than the rate of methane production, there may then be a tendency for the development of acidity. Acidities greater than pH 6.4 markedly interfere with methane fermentation and higher acidities (pH 5.5 to 6.0) retard, and may even stop the breaking down of the proteins.

For best results, therefore, digestion tanks should be operated to maintain a slightly alkaline reaction. The presence of carbohydrates in any appreciable quantity markedly accentuates the tendency toward acidity, whereas the presence of alkaline salts, such as are found in hard waters, or of humus-like bodies associated with well digested sludge, serves as a buffer against the development of detrimental acidities.

As a remedial and control measure the increments of fresh solids added should be restricted to a point where the acidities developed in the first stages of decomposition will not exceed the buffer value of the water and the sludge.

Loadings

This brings us to a consideration of digester loading, which might preferably be referred to by the expression of "lb. of dry solids added per cu. ft. of tank capacity, per 30-day period." Such loadings at Cedar Rapids, Iowa, for example, have been increased from an average of 4.3 lbs. of dry solids added per cu. ft. per 30 days to 5.5 lbs. for a 30-day period, 6.4 lbs. for a 15-day period and as high as 9.0 lbs. for a shorter 5-day period.

A composite study of peak loads, obtained from data taken at Chicago, Cleveland, Columbus, Syracuse, Rochester and other large American cities, as assembled by R. A. Alton of Columbus, Ohio, results in a curve showing maximum raw sludge production varying from about 140 per cent over a 40-day period up to about 400 per cent for a 2-day period.

Again, loadings must be considered in respect to volatile solids for, as W. Vincent Barry, City Engineer of New Haven, Conn., has so graphically illustrated recently, the percentage of volatile solids in the total (settleable) suspended solids (after 2 hours detention) is but a fraction of those available in the total solids of a medium strength sewage. It is further of interest to note that the reduction of solids by digestion, as expressed in terms of volatile solids reduction, depends largely upon the per cent of volatile matter in the material fed to the digester. For example, with only 60 per cent of volatile solids in the raw sludge, reduction of the original volatile matter in the digested sludge when ripe is only about 47 per cent; whereas with 70 per cent volatile in the raw, a reduction of about 67 per cent may be anticipated, based upon results as reported at 14 typical sewage treatment plants.

Operation

Sludge additions should be made to each primary digestion tank as frequently as possible or as is feasible. By adding smaller quantities at more frequent intervals, a more constant food supply is afforded the bacteria and a more uniform gas production is obtained, which indicates a more uniform rate of digestion.

Sludge withdrawals should be made in small increments, drawing only one sludge bed or less at a time. It has been noted that frequently when operators find a digestion tank loaded with solids, with little supernatant liquor present and a preponderance of so-called "floating sludge" on top, they resort to withdrawing a large quantity of low volatile content or digested sludge from the bottom of the tank. The result is generally an aggravating of the situation due to an upsetting of the tank balance with an increase in the "floating sludge" layer both as to thickness and concentration.

In a two-stage system care must be exercised in transferring material from the first or active tank to the second or concentrating-separation tank. Best digested solids should not be depleted since they are necessary not only for seeding and buffering of the added raw solids, but act as a "roughage" material recently found necessary for proper environment for the organisms to work effectively.

In the operation of digesters, lime is commonly employed as a means of pH control, and it has been recognized that frequently such application of lime has been overdone. It must not be overlooked that its application may increase the volatile acids, and also that it may have bactericidal properties, thus harming rather than assisting in the desired tank activity.

We would stress the importance of never losing sight of the fact that each plant is a distinct and individual problem and that the methods of operation for any particular plant must be proven empirically. This is not to say that certain fundamentals of operation do not apply; as long as they are fundamentals,—as long as they conform to the biochemical requirements—they may properly be practised. As a case in point, the maintenance of liquefactive conditions is fundamental. This state may have to be maintained artificially in respect to the scum or top sludge zone. Constant scum submergence is imperative, and the introduction of hot supernatant liquor or sludge taken from the active zone of a tank is in a majority of cases found extremely effective as an operational measure, as pointed out by Buswell in his application for patents covering such practice.

Loadings and the per cent of available volatile material will both be reflected in the gas production, with respect to total quantity and rates of production. In this connection, gas production can effectively be reported for the records in terms of cu. ft. per lb. of volatile solids added, as well as per cu. ft. of tank capacity per 30-day period, and in this way be tied in with digester loadings, based on either total or volatile solids, in lb. per cu. ft. per 30-day period.

The importance of the maintenance of ample buffer material in the form of relatively well digested sludge; the reasonably prompt intermixing of fresh material and sludge or sludge liquor containing large numbers of virile micro-organisms of the types we have been considering as necessary; the maintenance of proper temperature and the immediate removal of the gas produced, on account of its poisonous reaction and drying effect and thus retardation of the digestion process; these are matters of a practical nature, which must be considered, and it is hoped that their importance will be better understood, in the light of the preceding theoretical considerations.

In conclusion, it is suggested that you carry back with you the thought that, due to the basic theoretical work done to date, we are on the threshold of a new era in the science and art of sludge digestion. We have reached a point where we can, in a practical manner, think in terms of controlling biochemically these reactions of natural law.

REFERENCES

1. Hotchkiss, M., "Studies on the Biology of Sewage Disposal." *J. Bact.*, 9, 455 (1924).
2. Warburg, O., Berlin (1928).
3. Wieland, H., and Berthe, A., *Ann. de Chemie*, **467**, 95 (1928).
4. Waksman, S. A., "Principles of Soil Micro-Biology," Second Edition. Williams and Wilkins.
5. Bach, H., Chemist, Berlin.
6. Levine, Max, "Bacteriological Aspects of Sewage Treatment" (1938).

OPERATION OF SLUDGE DRYING AND SLUDGE GAS UTILIZATION UNITS*

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I. SLUDGE DRYING

The purpose of sludge drying is to reduce the volume and water content of liquid sludge for easier handling. Liquid sludges commonly contain 85 to 95 per cent water, and may be dewatered by various drying processes to 50 to 80 per cent moisture without the use of heat. The most common moisture content of dried sludge is in the range from 60 to 70 per cent. This reduction in moisture will frequently reduce the sludge volume to about 1/5 of the original. The resulting sludge cake, having the consistency of moist earth or chopped damp cardboard, may then be used as fill, as a soil conditioner with or without heat drying (with heat drying, the moisture content is further reduced to 10 per cent or less), or it may be incinerated to an inert ash. While the incineration of wet sludge has been tried, the process must still be considered in the experimental stage.

* Presented at Lecture-Laboratory Course on Sewage Treatment and Disposal, sponsored by Pennsylvania Sewage Works Assn. at St. Joseph's College, Philadelphia, Pa., on May 9, 1945.

Conditioning of Sludge Prior to Drying

The use of any process for sludge drying is invariably preceded by some form of sludge conditioning. The purpose of sludge conditioning is to promote the more rapid removal of water from wet sludge by aiding in the separation of the solids and liquid. The following conditioning processes may be employed:

1. Sludge digestion.
2. Chemical coagulation.
3. Elutriation.
4. Thickening.

Sludge Digestion

Sludge digestion is a form of sludge conditioning whereby the characteristics of the raw sludge are so altered that dewatering on beds of sand may be accomplished in less time and without nuisance. By the digestion process the original volatile matter is reduced by 50 per cent or more, producing so-called "ripe" sludge.* Such sludge has a tarry odor, is black or dark brown in color, produces a clear liquor when settled in a tall cylinder, is near the neutral point in pH value, drains freely and thereby produces cake cracks within a few days on sludge drying beds so that evaporation of the remaining free moisture is hastened. Another aid from the digestion process is that the entrapped gas under hydrostatic pressure and in solution in the bottom sludge of digesters is released when it is drawn to drying beds. This gas buoys the sludge particles and they float. The sludge becomes foamy. Thus the sludge liquor seeps quickly into the sand before it is clogged by the solid particles. Operators may observe this characteristic of live ripe sludge by collecting a sample in a tall cylinder. If the sludge remains on the bottom with a yellowish, turbid top water, the sludge is probably not sufficiently digested. Without sludge conditioning in digestion tanks, the use of sludge drying beds for dewatering would be prohibitive under most conditions. In the case of vacuum filtration of sludge, digestion provides storage for sludge, less odor, longer cloth life, more uniform feed for incinerators, reduced sludge volumes with resulting reduction in filtering hours, and frequently reduces the chemical costs for coagulation.

Chemical Coagulation

This conditioning process of sludge is a necessity in vacuum filtration and sometimes has a place in sludge dewatering on sand beds.

* In computing the per cent reduction in volatile matter of raw sludge by digestion, operators should use the following formula for correct results:

$$\text{per cent reduction} = \left(1 - \frac{\text{per cent fixed in raw} \times \text{per cent volatile in digested}}{\text{per cent volatile in raw} \times \text{per cent fixed in digested}}\right) \times 100$$

Example: Raw sludge having an average analysis of 60 per cent volatile and 40 per cent fixed solids contains after digestion 30 per cent volatile and 70 per cent fixed solids. The per cent reduction in volatile matter is therefore:

$$\left(1 - \frac{0.40 \times 0.30}{0.60 \times 0.70}\right) \times 100 = \left(1 - \frac{0.12}{0.42}\right) \times 100 = (1 - 0.29) \times 100 = 71 \text{ per cent Ans.}$$

Ferric chloride with or without lime is most frequently used for vacuum filtration, and alum for sludge bed conditioning. Briefly, "these precipitants form a relatively insoluble floc which in-meshes suspended and colloidal particles mechanically or adsorbs them upon its large and sticky surface, or by ionization the electrical charges are neutralized on colloidal particles causing their coagulation." * More specific reference to chemical coagulation will be made under vacuum filtration and sludge bed drying.

Elutriation

Elutriation means a washing of digested sludge with water to remove the soluble amino and ammonia compounds in the sludge, thereby eliminating the use of lime in vacuum filtration and reducing the amount of ferric chloride required for proper chemical coagulation.

Thickening

Lastly, thickening in either special concentration tanks or sludge storage tanks is a sludge conditioning process sometimes used to aid dewatering by increasing the solids content of the sludge. In vacuum filtration this is of value since sludge liquor has a chemical demand which is reduced in proportion to the reduction in the volume of liquor. Other factors, however, limit the extent to which sludge concentration is feasible. In general, the optimum range for raw sludge filtration is about 6 to 8 per cent solids and for digested sludge 8 to 15 per cent solids. When elutriation of digested sludge is employed, the solids content must frequently be held below the above range or the filter sludge cake may be too wet.

Where unheated sludge storage tanks are provided in conjunction with heated digestion tanks, such tanks will increase the solids content of the sludge, resulting in a thicker sludge cake on drying beds for a given depth of application of the wet sludge.

Processes for Sludge Drying

The water in wet sludge may be partially removed without heat by:

1. Drying on beds of sand.
2. Vacuum filtration.
3. Mechanical presses.
4. Centrifuging.

With heat, two additional processes may be used generally in conjunction with vacuum filtration as a first step:

1. Commercial drying to 10 per cent or less of water.
2. Incineration of the sludge to an inert ash, utilizing the sludge as a source of fuel with or without the aid of fuel oil or sludge gas.

* From "Sewage Treatment" by Karl Imhoff and Gordon M. Fair, John Wiley and Sons, Inc., New York, 1940.

Sludge Drying Beds

Briefly, these beds are constructed of an under-layer of graded gravel with at least 6 in. of top sand. The beds are generally underdrained and may be open to the atmosphere or glass covered. As this paper is not intended to discuss design features, the following remarks are limited to operating problems.

Sludge beds should be resanded when half the original sand depth is lost. All dirty sand should be carefully removed and the new sand should be as near as possible of the same uniformity and coarseness as the sand originally used. Sand coarser than the original might permit solids to pass down to the old sand layer where they would not be accessible for removal, causing sub-surface clogging. Too fine a sand or a dirty sand will retard drainage. It is generally specified that sand used for this purpose should be washed, have a uniformity coefficient of 4.0 or less, and an effective size between 0.3 and 0.5 mm. When resanding, a depth of at least 12 in. (provided sufficient free-board is available) will produce a superior effluent and reduce the frequency of resanding. If a similar sand cannot be obtained, the old and new sand should be well mixed in place by harrowing or other means, or all of the old sand should be removed.

To enhance flexibility in operation, a group of small sludge beds is better than a few large beds. Large beds may be easily divided by sinking creosoted wood planks in the sand or by making ridges of the sand itself. Dosing depths and cleaning schedules are aided by the flexibility thus afforded.

Regarding dosing depths, operators soon learn that light doses of wet sludge mean extra labor for cleaning per pound of dry solids removed. Likewise, too great a depth seals the sand with solids before all of the sludge liquor drains off. The excess moisture remaining must then be removed by evaporation, a phase of sludge drying which is much slower and which therefore delays cleaning of the bed. While the best dosing depth varies at different plants, in general a depth of 8 to 10 in. will give the best over-all results.

The operator should always bear in mind that drying time is increased by each inch of dosing depth, and also by each percentage increase in dry solids of the wet sludge. Thus, with average good drying weather, a wet digested sludge of 5 per cent solids applied to a depth of 8 in. can be forked in about one week, while a sludge of 8 per cent solids applied to the same depth will require about two weeks. If applied to a depth of 10 in. the time will be increased about 3 and 9 days respectively. It always bears repeating that wet sludge should never be applied to a bed containing partially dried sludge, since the sand is sealed with solids and drainage will be poor. Reference to a previous remark on the value of entrapped gas in ripe sludge will serve to emphasize the wisdom of this advice.

Other factors affecting the drying time include the degree of digestion of the sludge, amount and time of rainfall after application, the

intensity of wind, hours of sun, temperature, the relative humidity and the design features of the drying bed.

Careful measurements at Johannesburg, South Africa have revealed some interesting data on sludge drying. It has been found that 60 per cent of the total sludge volume is removed as effluent water by the beds. Drainage through the sand is negligible after the first 24 hours. If drainage from the beds were prevented it would require 9 days to remove the volume of drainage water by evaporation alone. Regarding rainfall on open beds, the following observation at this plant is of interest to operators:

> "The effect of rain is not so considerable as is generally supposed and varies according to the length of time the sludge has been on the bed before the rain. When rain falls before drainage has stopped, all the rain passes right through the sludge and the bed, just as though there were no sludge. There is no tendency to absorb the rain. When rain falls after drainage is complete and while evaporation is a major factor, the rain does not drain through the bed but is absorbed by the sludge. The cracks are reduced in size and the drying time is increased. When rain falls after the sludge is thoroughly dried out and the cracks are large, extending down to the surface sand, it is not absorbed to any large extent by the sludge but flows rapidly through the bed."

Operators with glass enclosed beds have certain obvious operating aids. By closing the sash during the first 24 hours of drainage and at night for a few days, odors are largely prevented from carrying. In spring and fall, when rains are more frequent and the rays of the sun weaker, enclosed beds aid drying. In winter, the sludge is protected from snow and the operator may remove sludge, even if frozen, in comfort. In summer, evaporation is likely to prove slower from enclosed beds than open beds, suggesting the advantage of a combination of open and closed beds. The future may see more use of heated enclosed beds coupled with forced ventilation to promote evaporation.

Maintenance of enclosed beds includes replacement of broken glass, keeping the hardware in good working order and painting. A word about painting. The usual coatings used are a red lead primer with a finish coat of aluminum. At Greenwich, Conn., a single coat of a black bituminous paint has proven superior for the interior surfaces, where moisture and the presence of sludge gas always create a painting problem.

When drying bed area is inadequate for the required dosing schedule or the sludge cannot be well digested, many operators fail to realize the aid that chemical coagulation may provide. From 6 to 10 lb. of alum applied as a solution to every 1,000 gal. of wet sludge just as it is discharged to the drying bed will hasten the drying of most sludges. Sludge so treated is less affected by rain, cracks sooner, and contains a higher percentage of dry solids, thereby reducing cleaning costs and increasing the number of sludge drawings per bed per year. Sperry * has ably described the method. Ferric chloride may also be used as a

* "Alum Treatment of Digested Sludge to Hasten Dewatering," Walter A. Sperry, THIS JOURNAL, September, 1941, page 855.

coagulant but its continued use may eventually clog the sand with oxidized iron.

The keeping of *accurate* records on sludge drying is a chore that will repay operators in better utilization of sludge beds. As with many phases of sewage treatment, complete records, intelligently interpreted, are of real value.

The manner of removing sludge cake from drying beds naturally varies with the facilities provided in the design. Among the aids available, the use of a side bin or "saddle-bag" tractor * is worthy of consideration.

Vacuum Filtration

The modern vacuum filter is a rotary drum under vacuum, suspended in a trough which contains conditioned sludge ready for filtration. It is impossible to discuss fully the mechanics of vacuum filtration in an article of this length. The writer has previously reviewed the subject in detail from the operators' standpoint.† Reference to these articles will, it is hoped, guide operators unfamiliar with the problems involved. The following remarks will serve to summarize a few of the more important factors involved:

Most filtering difficulties may be traced to improper sludge conditioning. The sludge is conditioned for vacuum filtration by chemical coagulation with or without the use of elutriation, digestion, or thickening. Sludge conditioning should be regularly checked in the laboratory with a Büchner funnel. The detailed procedure for making such tests is described in the writer's previously mentioned articles.‡ This test is a check on the sludge, reveals blinded filter cloths, determines best order of addition of the conditioning chemicals, saves chemicals and has many other uses.

In raw primary sludge filtration, freshness of the sludge is important. Stale or septic sludge increases chemical costs, produces offensive odors, and gives rise to filtering difficulties.

Continuous-mix conditioning tanks of short detention with gentle mechanical stirring of sludge and chemicals have proven superior to the batch-mix method. Gravity flow of conditioned sludge to the filter vats is also superior to mechanical handling.

Filters requiring wire windings for cloth support are now generally wound with No. 12 steel wire or No. 14 bronze wire.

Idle filters with wooden drums should be rotated daily in water to prevent shrinkage of the drums with resulting loss of vacuum when started.

As filters age, reconditioning of the supporting mesh for the cloth and of the interior piping will be required. Wet blinded areas on the

* "Reducing the Cost of Sludge Removal" by Walter A. Sperry, *Water Works and Sewerage*, August, 1941, page 345.

† "Vacuum Filtration of Sludge" by LeRoy W. Van Kleeck, *Water Works and Sewerage*, March, June, July, August, and October, 1939. Also THIS JOURNAL, November, 1938, page 949.

‡ See *Water Works and Sewerage*, August, 1939, page 311.

cloth reveal a clogging of the mesh or piping. The problem is more acute when lime is used. Scrubbing the mesh with a stiff brush dipped in acid oakite or diluted hydrochloric acid will relieve the condition temporarily, but eventually the mesh must be removed, and either sand blasted or soaked in hydrochloric acid with an inhibitor added. If accessible, the piping may be reamed out, but if badly clogged the most satisfactory remedy will be new piping. Chemical treatment of piping has not proven worth-while in the writer's experience.

Operators should give more consideration to the various types of filtering cloth available. There is a cloth best suited to your conditions. Among the cloths obtainable are:

1. A thin cotton cloth without nap, especially suitable for raw primary sludges.
2. A heavy cotton cloth without nap, suitable for raw or chemically precipitated sludges.
3. A cotton cloth with nap for digested primary sludges.
4. Wool cloths for activated or elutriated digested sludges.
5. A chemically treated cotton cloth without nap for sludges requiring an excess of lime in conditioning.
6. A glass cloth for sludges containing an abnormal percentage of ferric chloride.
7. Monel metal cloth for highly alkaline sludges.
8. Synthetic cloths for all types of sludges.

Cloth maintenance is an important phase of filter operation. The life of cloths will be lengthened by:

1. Proper scraper adjustment (which also results in a cleaner cloth during filtration).
2. Use of the optimum amount of chemicals for conditioning. Doses can be too high as well as too low. High doses ruin cloths.
3. Wash the cloth with water under pressure after each filter run. At regular intervals brush the cloth with an oakite or soap solution to remove grease. If lime is used, wash the cloth thoroughly at least once with diluted hydrochloric acid containing an inhibitor. This acid wash should not be used until the cloth shows definite signs of being clogged.
4. Protect the cloth from the direct rays of the sun.
5. When changing cloths, apply the proper stretch and wire tension to the material.
6. Idle cloths subject to mildew may be protected by application of a formaldehyde or copper sulfate solution.
7. Promptly patch small holes in the cloth.

After following these precautions, when a cloth filters poorly, discard it. The cost of power and additional chemicals required to filter the sludge through clogged cloths is much more than that for a new cloth.

The postwar era will undoubtedly see improvements in vacuum filters. Among these improvements are likely to be the following:

1. Interior piping will be made more accessible for cleaning or replacement.
2. Wire wrapping of the cloth will be abandoned. (The string filter accomplishes this at present.)
3. Better distribution of the conditioned sludge in the filter vats will be provided by transverse (rather than longitudinal) agitators.
4. There will be a fuller realization that digestion of sludge prior to filtration pays dividends that soon liquidate the installation charges for digesters. (If the sludge will not digest because of industrial wastes, that is another story.)

Mechanical Presses

Sludge may be dewatered in leaf filters. Such filters are generally made of metal plates covered with cloth. The liquid sludge is fed into a compartment and subjected to a pressure of about 100 p.s.i. for varying lengths of time. The plant at Providence, R. I., has used this method of dewatering for many years. Air and vacuum drying have proven so superior, however, that the method has never become popular in this country. The writer knows of no new installations in recent years. As late as 1942, however, the McGlaughlin Patents, Inc., developed a filter press for sludge dewatering along new principles and more may be heard of this process after the war.

Centrifuging

The array of mechanical equipment required for vacuum filtration and the area requirements for air drying, have prompted many alert minds in our profession to develop a centrifuge for sludge dewatering. The only equipment required is a high speed centrifuge machine, powered by an electric motor. Machines have been developed for dewatering sludge at rates from 50 to 200 g.p.m. In 1938 the writer observed a series of tests made on a raw primary sludge containing 8 per cent solids. The sludge cake contained 33 per cent solids or 67 per cent water. The difficulty that developed was an effluent from the centrifuge containing 5 per cent solids of which 41,000 p.p.m. were in a finely suspended form. Such results are not materially different from results of other centrifuge trial runs. Obviously, a process which returns such a high percentage of the original solids to the sewage settling tanks will not work. Fine solids build up in the tanks until the system is literally choked with them. The future may bring developments, possibly through application of chemical coagulation to either the sludge feed or the centrifuge effluent.

Commercial Drying

The Raymond or Combustion Engineering Co. cyclone flash-drier is used for commercial drying. Vacuum filtration of the sludge precedes the process, which produces a powdery sludge of 10 per cent or less

moisture. The equipment and process has been fully described by Velzy * and Dundas.* Quoting from Dundas, the process in brief is:

"Flash drying is a continuous operation in which the sludge in a finely divided state is dried instantaneously in a hot gas stream. At Chicago a mixture of superheated water vapor and other gases is used as the drying medium. The temperature of the drying medium as it enters the system is approximately 1,100° F., and the velocity is approximately 5,000 f.p.m. At this temperature the evaporation of the moisture is almost instantaneous, and the passage through the drying cycle is a matter of seconds. Research by F. W. Mohlman has shown that dried sludge from a flash-drying system shows practically no trace of pathogenic organisms. The sludge never reaches a temperature sufficiently high to affect any of the properties valuable as fertilizer. The average temperature of the dried material as removed from the drying system is approximately 180° F. The temperature of the vapor and gases vented from the drying systems to the furnaces for deodorization is approximately 350° F. The drying systems are operated slightly under atmospheric pressure to prevent the escape of dust and gases. All operations are automatically controlled. The sequence is as follows:

"Sludge cake † containing 78 to 85 per cent moisture as discharged from the filters is conveyed to individual mixers where it is mixed with sufficient sludge, previously dried in the system, to reduce the moisture content and prepare a non-sticking friable mass. In this form the sludge is introduced into the drying system, where it is picked up in the high-velocity, high-temperature gas stream. A cage type of disintegrating mill interposed in the drying circuit breaks the sludge into small particles, causing maximum exposure of wet surface and complete dispersion of the particles in the drying medium. The sludge particles carried in the superheated vapor and gaseous drying medium are discharged into a cyclone separator where dried sludge is separated from the vapors and gases in which it was conveyed. Part of the sludge removed from the separator is returned to the sludge mixer, and the surplus is withdrawn as fertilizer material or pneumatically conveyed to a separate furnace where it is burned in suspension."

At the Stamford, Connecticut, plant this type of drier is normally supplied with heat from the gases of combustion of a refuse incinerator. Sludge gas and fuel oil are both available as stand-by fuels. The sludge may be burned after drying, if desired, in the refuse incinerators or it may be removed from the system in the dried form for use as soil conditioner and fertilizer. This method by utilization of otherwise wasted heat has much to commend it.

The principal advantages of heat dried sludge are:

1. Reduced weight for hauling as soil conditioner or fertilizer.
2. Better spreading characteristics for use on land.
3. If desired, the sludge is sufficiently dried for complete destruction of organic matter by incineration in either a sludge incinerator or refuse incinerator.

In the operation of flash-drying equipment operators must possess mechanical aptitude and dexterity. The equipment is high speed in character and requires proper lubrication of moving parts, temperature control, and careful synchronization of the various controls. Abrasive action on the metal passages from the fines and grits in the sludge has been one of the main operating problems with these driers. By easy

* "Dewatering, Incineration, and Use of Sewage Sludge—A Symposium," *Proceedings*, American Society of Civil Engineers, January, 1943, page 41.

† Activated sludge in this case.

replacement of those parts subject to wear, this problem has been largely overcome. The ease with which this type of equipment may be brought up to temperature and shut down has been one of its most desirable features, especially for plants where a 24-hour filtering schedule is not required.

Incineration of Sludge

While the writer has always felt that failure to use dried sludge as fertilizer is a waste of a natural resource, there are unfortunately some circumstances where its destruction to an inert ash is the only economical means for disposal. This is particularly true in large cities having primary raw or digested sludges having too low a nitrogen content to command a good market price.

Incineration must take place in furnaces especially designed for the job; otherwise, an odor nuisance will result, coupled with incomplete combustion of the organic matter. Two types of furnaces are commonly used. One is the Raymond furnace mentioned above which burns, in either a separate furnace compartment or a refuse incinerator, sludge previously dried to 10 per cent or less of moisture by the flash-drying unit; the other is the Nichols Herreshoff furnace.

The Nichols Herreshoff furnace consists of a steel shell, lined with fire-brick and containing a series of hearths (generally 6 to 8) over which the sludge is mechanically conveyed by rabble arms from hearth to hearth. The wet sludge cake from the vacuum filters enters this type of furnace at the top.

The upper hearths serve to dry the entering wet sludge cake by exposing it to the hot escaping gases of combustion from the dried sludge burning on the center hearths. The bottom hearths cool the ashes of combustion and the ash is mechanically removed at the bottom to an ash hopper. Auxiliary fuel is furnished by oil burners or sludge gas. When burning raw sludge the volatile content is frequently sufficiently high to provide all the fuel required for combustion once the furnace has been brought up to its normal operating burning temperature of 1,400 to 1,600° F. Digested sludge cake usually requires some auxiliary fuel for burning.

This device is a relatively slow speed machine as compared with the Raymond equipment. Abrasion of moving parts is not a problem, but hearth and furnace wall repairs are generally necessary after a period of operation. Proper operation and reduced maintenance cost depend in large measure on providing a uniform filter cake feed to the furnace so that over or underloading does not occur, maintaining the proper internal burning temperatures, and keeping the drive mechanism and ash removal equipment in good mechanical order.

The ash from sludge incineration is usually 97 to 98 per cent fixed solids and very few bacteria survive the heat. The ash may be used as fill, for sanding icy surfaces or in foundry work for castings.

II. SLUDGE GAS UTILIZATION

The utilization of the gas produced by the digestion of sewage sludge probably has more popular appeal than any other phase of the art of sewage treatment. It has been reported that perhaps the first use of sludge gas was in Exeter, England, in 1895, when Mr. Cameron, the Borough Engineer, used it in a street lamp for lighting. In the first two decades of the present century the Imhoff tank was widely adopted for the digestion of sludge and it was not until about 1920 when separate sludge digestion became the trend that sludge gas utilization came into its own.

Composition and Amounts of Sludge Gas Produced

Sludge gas is a mixture of gases consisting largely of methane (about 65 to 70 per cent by volume), carbon dioxide (25 to 30 per cent), nitrogen (about 5 per cent) and small quantities of hydrogen, hydrogen sulfide, and oxygen. Occasionally traces of carbon monoxide or phosphine may be present. The combustible constituent is chiefly methane; the hydrogen content, while small, has some effect on the heat value. The heat value varies almost directly, therefore, with the methane content and averages about 640 B.T.U. per cu. ft. of gas as produced in separate sludge digestion tanks in the U. S. In Europe the heat value is nearer 740 B.T.U.

The average yield of gas in the United States from plain sedimentation sludge is about 0.8 cu. ft. per capita per day. The range is from 0.5 to 1.3 cu. ft. per capita per day. A more accurate average figure is about 18 cu. ft. of gas per pound of volatile solids destroyed. When either humus sludge from trickling filters or activated sludge is added, the average yield is increased to about 0.9 cu. ft. per capita daily.

Collection of Gas

Before sludge gas can be utilized it must be collected *and collected safely.* A complete discussion of the proper method of gas collection in sewage treatment plants may be found in Manual of Practice No. 1, F. S. W. A., pp. 28–30.

Briefly, the gas may be properly removed:

1. Directly from a floating cover digester.
2. From a fixed cover digestion system:
   (a) With a gas holder riding on the gas system and digestion tanks to fill any voids created by drawing off the contents of the digesters.
   (b) With digesters operated in series, with the secondary unit equipped with a floating gas holder riding on the system.
   (c) With positive automatic means of maintaining the digesters at the overflow level to prevent voids during sludge drawing and the possibility of sucking air into the digesters and gas

system. At older plants lacking such positive means, the gas should be shut off, and the gas dome manhole opened during sludge drawing. The digester should then be immediately refilled with raw sludge or liquor to the overflow point before resuming gas collection. Sometimes it is possible to pump sludge or liquor to the digester at a slightly higher rate than the digested sludge withdrawal rate to maintain the tank full.

The gas piping layout should provide for a main gas collector at least 2 in. in diameter, the gas inlet being well above the digester scum line, with the take-off pipe inside the digester or underground to prevent freezing of the condensate, and pitched to an operating gallery with an *approved* condensate trap installed at the lowest point on the piping. The gas should then be *metered* and an approved factory-built flame trap installed *within 25 feet* of all units utilizing the gas. The waste gas burner system should be provided with a meter, pressure regulator, flame trap and condensate trap, the latter again being at the low point of the system. If the gas pipe layout does not provide these safety features, *this is one feature of plant design the operator should change at once.*

Gas manometers should be more generally employed on gas collection systems. These devices indicate the gas pressure in inches of water. A master manometer or individual units should be provided to give the gas pressures at the following points on the system:

1. At the take-off of the digestion tank.
2. Before and after gas meters, flame traps, and pressure regulators.
3. Just ahead of gas boilers, engines or other devices used for gas utilization.

Manometers enable an operator to operate intelligently the gas collection system; they indicate excessive pressure losses through meters and traps, and provide a means for indicating gas leaks. Manometers are easily installed, if the system is not now provided with them.

The gas piping should be flushed occasionally with water or disconnected, if necessary, to remove deposits. In dismantling piping the operator should guard against the possibility of spontaneous ignition of iron sulfide that may be deposited in the piping and which may cause burns or a fire.

Gas meters are of the diaphragm or rotary type. They should be cleaned yearly and the casings replaced if cracked. Moving parts should be lubricated and if water has accumulated in them, a condensate trap should be installed just ahead of them.

Condensate traps should also be cleaned yearly and checked periodically for leaks with an explosimeter. The approved manually operated condensate traps now available have a spring adjustment for tightening if leaks develop. Under no circumstances should U-tube

or other devices having openings inside structures be used for condensate traps. Serious explosions have been caused by their use in the past.

Flame traps and pressure relief traps also need yearly cleaning and inspection. The flame element, generally composed of aluminum strips, should be blown out with air, soaked a day in dilute hydrochloric acid, rinsed, and thoroughly dried before re-assembling. If it is badly corroded it should be replaced. The spring-actuated shut-off mechanism should be lubricated with a few drops of light oil every few months. If the thermal link melts and requires resetting, this is easily accomplished by using a solder of 50 per cent tin and 50 per cent lead with a melting point of about 400° F. The link is reset by melting a portion of solder in the bottom of the plug. The link should be held perfectly still until the solder adheres to it. Incidentally, be sure that flame traps have been installed with the fusible plug *toward* the source of flame. They have been placed backwards more than once by inexperienced contractors. Flame traps should never be provided with bypasses. If the trap is down for repairs, do not attempt to utilize the gas.

Perforated gas pipes submerged in water or metal gauzes of the type used in the "Davy Lamp" cannot be considered as approved flame traps. Even with 6 or more inches of water submergence, a flame may pass through the water. Furthermore, the water used with such a device may be "blown out" or it may evaporate. Excessive gas pressure losses also occur. The "Davy" type of trap quickly becomes overheated and the need of reasonably fine gauze is likely to result in a clogging of the gauze with foreign matter from the gas or in its corrosion by hydrogen sulfide. These points are mentioned as a caution against the use of all home-made devices. Use factory approved types and play safe.

All gas appurtenances and piping should be checked periodically for gas leaks by using an explosimeter or, lacking such a device, by a soap bubble test.

Uses for Sludge Gas

The uses of sludge gas in the order of their most common occurrence are:

1. Heating digesters, generally by hot water circulation. Direct heating by steam jet or pre-heating of raw sludge in a high temperature heat-exchange jacket may be employed, but these methods are generally supplemental aids rather than all-sufficient for digester heating requirements.
2. Heating treatment buildings (steam or hot water).
3. Laboratory use (gas direct).
4. Operating gas engines which in turn are coupled to sewage pumps, air blowers, or electric generators (scrubbed or unscrubbed gas direct).

5. Source in whole or part for incineration or drying of sewage screenings or sludge (gas direct).
6. Refrigeration (gas direct).
7. Lighting (gas direct).
8. Motor fuel in trucks. Gas compressed to about 5,000 lbs. per sq. in. pressure. About 19 cu. ft. of gas will drive the average truck one mile, hence 170 cu. ft. is equal to about one gallon of gasoline.

The heating of digesters and buildings involves the use of gas boilers discussed below. Gas engines are also discussed more fully below. Laboratory use refers to burning of the gas for heating water baths, drying samples, etc. Some plants have constructed small high-temperature incinerators equipped with a gas burner for the destruction of organic matter in sewage screenings. Their use is not general. Stored gas is commonly used as auxiliary fuel in the drying or incineration of sludge at plants using this process. Gas refrigerators have been successfully operated by sludge gas. Lighting with sludge gas has little if any utilization in this country; it is used to a small extent in Europe. Likewise, the use of gas for motor fuel has been limited to a few locations in England and Germany.

Gas Boilers

The average gas boiler used in sewage plants is a hot water tube unit of steel or cast iron which may or may not be lined with firebrick. The burner units are generally of either the orifice or gun type.

As the number of sludge gas-fired boilers has increased in sewage treatment plants, interest in their proper maintenance has quickened. One of the important maintenance problems is the prevention of boiler corrosion or rusting.

Internal corrosion is caused by the metal going into solution in the boiler water. The iron "rusts" or unites with oxygen and hydrogen or with oxygen alone to form compounds. Some iron is almost sure to go into solution, but the higher the pH of the boiler water the less will dissolve. A pH of 11.0 to 12.0 obtained by adding an alkaline salt such as sodium hydroxide to the boiler water, coupled with the removal of as much oxygen as possible, will greatly control corrosion. The higher the boiler water is heated where there is good venting, the less oxygen it will contain. A minimum water temperature of 160° F. at the boiler is recommended.

High combustion chamber temperatures prevent condensate formation and corrosion on the outside of the boiler pipes and frame. An internal boiler temperature of at least 300° F. is usually considered desirable. In locations where water has proven very corrosive in boilers, the use of sodium sulfite is frequently necessary. From 20 to 50 p.p.m. of this chemical gives a sufficient excess to protect from oxygen. The sodium sulfite combines with oxygen to form sodium sulfate, thus:

$$2Na_2SO_3 + O_2 = 2Na_2SO_4$$

It is suggested that operators interested in this problem write to the U. S. Department of the Interior, Bureau of Mines, Washington, D. C., and ask for "Question and Answer Handbook No. 3" on "Boiler Feed-Water Conditioning."

In addition to control of corrosion, the safety devices on boilers should be regularly checked. These include:

1. The water level in the boiler.
2. The water temperature (aquastat control).
3. The pilot light safety cut-off.

A few remarks are in order regarding the latter. The thermo-mechanical type of cut-off for the main gas supply, if the pilot goes out, requires frequent checking and such devices generally operate too slow or not at all after a few years. Because of the serious hazard of non-ignited gas entering the boiler chamber under such conditions, operators should be sure of the proper functioning of these devices. While more expensive, the most positive type of safety control for pilots is the so-called "Brown Protectoglo" system. In this system, the pilot flame is part of a closed electrical circuit and the main gas supply is positively shut off if the flame goes out by the breaking of this circuit. The gas-feed orifice on pilots requires regular cleaning to remove deposits and the corrosion that is bound to occur. A weak pilot flame is a hazard.

Gas Engines

Sludge gas engines may be standard gasoline-type engines with the carburetors removed. In fact engines are available that will operate on the turn of a valve by either gasoline or sludge gas. Engines of stationary type, however, which are heavier and of slower speed than gasoline engines, will give greater economy in operation and freedom from maintenance. Excellent articles on gas engine maintenance include one by W. B. Walraven, Engineer for the Springfield, Ill., Sanitary District, in *Municipal Sanitation* magazine (now *Sewage Works Engineering*), November, 1936, and one by Samuel A. Greeley and C. R. Velzy in the January, 1936, issue of THIS JOURNAL. Review of these articles is recommended.

Fuhrman * reports 83 gas engine installations in the United States in 1940, totaling 22,170 h.p. Most of these were installed during the period from 1935 to 1940. They operate air blowers in activated sludge plants, sewage pumps, or drive electric generators to produce power for plant use. In addition, exhaust heat recovery boilers may be used for hot water circulation for buildings or digestion tanks. The hot water efficiency of gas engines is about 50 per cent, thus approaching that of the ordinary gas-fired boiler, which is 60 to 80 per cent.

When gas engines are employed, regular gas analyses should be made in the laboratory. Hydrogen sulfide usually creates a corrosion

* "Sludge Gas Utilization," Ralph E. Fuhrman, THIS JOURNAL, November, 1940, page 1087.

problem if it exceeds 0.1 per cent by volume. It is effectively removed, when necessary, by scrubbers. These are boxes filled with iron oxide sponge and through which the gas is passed ahead of the engines.

The engines should be kept clean, the proper oil used (oil purifying equipment usually pays for installations serving over 100 h.p.), the spark plugs kept clean, and scale regularly removed from the water jacket. The scale may be removed by filling the jacket for 24 hours with a 50 per cent hydrochloric acid solution, draining, and flushing. The valves of the engine need grinding several times yearly. Sludge gas is a so-called "lazy" gas and the engine spark must be well advanced for good ignition. Safety features include good ventilation in the operating room, periodic checking for gas leaks, and an automatic shut-off gas valve if the engine fails to fire.

The gross savings from gas engine installations make impressive figures at many sewage treatment plants. Installations of these units will undoubtedly materially increase, even in plants formerly considered too small for their economical operation. The combination gasoline-sludge gas-fired engines will make this possible, through elimination of present high standby charges for outside power connections.

In this discussion brief mention has been made of gas holders. When gas is utilized for gas engines or incinerating purposes, such holders should be provided. There are important considerations for the designer of such units with which the operator is not concerned. Maintenance includes painting, removal of accumulated condensate from the stored gas, and periodic testing of the pressure and vacuum relief devices. When the interior of holders must be inspected, careful purging is required. Instructions are given for this procedure on pages 40 and 41 of the before-mentioned Manual of Practice No. 1 of the Federation of Sewage Works Associations.

OPERATION OF ACTIVATED SLUDGE PLANTS*

By Gail P. Edwards

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The activated sludge process is widely used where a high degree of purification is required. It can be operated with complete freedom from odors and flies, on a minimum area of land. Pearse reported that at the end of 1942 there were 386 plants in the United States.

Theory

In nature, the decomposition of organic wastes is accomplished by the activities of bacteria and other micro-organisms which use complex organic materials as food and break them down into simpler, more stable forms. The organic substances contained in sewage form a bounti-

* Presented at Lecture-Laboratory Course on Sewage Treatment and Disposal, sponsored by Pennsylvania Sewage Works Assn. at St. Joseph's College, Philadelphia, Pa., on May 16, 1945.

ful food supply for the micro-organisms. When sewage flows over or comes in contact with a suitable surface, growths of bacteria and micro-organisms appear and soon cover the surface with a slimy gelatinous film. This film, which is full of life, has the extraordinary power of first attracting to itself substances that previously had been held in suspension, colloidal state or even in solution; then of removing from these attracted substances the food necessary for film maintenance and growth; and finally of returning to the sewage the end products of decomposition.

The activated sludge process is a method of sewage purification consisting of the aeration of sewage in the presence of biologically active sludge which has previously been produced by the process. It is a true biological contact process. The solids suspended in the sewage form the initial nucleus or contact surface to which the slime forming biological growth adhere. Large flocs of suspended matter are formed by

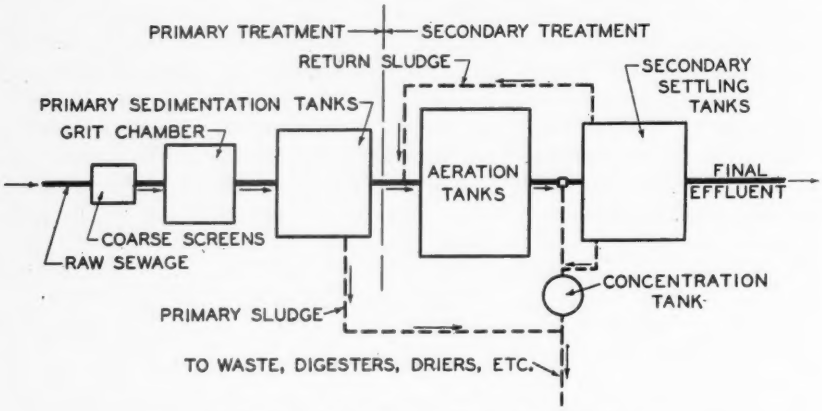

FIGURE 1.—Typical flow sheet of activated sludge process.

bacterial growth. By voracious feeding, the organisms in the floc cleanse or restore the active contact surfaces: hence they are called "activated" sludge flocs. This floc contains living, growing organisms which require oxygen for life.

Activated sludge, as defined by Donaldson, is a brownish gelatinous material consisting mainly of micro-organisms produced by the continued aeration of sewage. A flow diagram of a simple activated sludge plant is shown in Figure 1.

In practice, the sewage mixed with returned activated sludge flows through aeration tanks where air is added. From the aeration tanks, the effluent discharges into final settling tanks where the activated sludge settles out. Most of the sludge is returned to the aeration tanks to inoculate the sewage. The effluent from the final settling tanks is clear, free from color and odorless.

Aeration may be accomplished in several ways:

1. Diffused air aeration. Air is blown into the sewage as it flows through the tanks.
2. Mechanical aeration. Mechanical apparatus is employed to aerate the sewage and keep the solids in suspension. Absorption of air takes place at the surface of the liquid.
3. Combined use of diffused air and mechanical aeration. A reduced amount of air is blown into the sewage while mechanical apparatus keeps the liquid in circulation.

The material in this paper applies particularly to diffused air plants.

Starting Units in Operation

Before placing units in operation, tanks and pipe lines must be free of debris and all mechanical equipment in working order.

The most common method of starting an activated sludge plant in operation is by the continuous flow method. The sewage is allowed to flow through the tanks continuously and all sludge from the final tanks is returned to the aerators. Some purification will be obtained in a few days, but from one to three weeks are generally necessary to produce normal purification. When the concentration of suspended solids in the aeration tank has reached a satisfactory value, excess sludge should be withdrawn from the system at a rate which will keep the concentration of solids in the aeration tanks fairly constant.

Variables in Operation

The most important variables under the control of the operator of an activated sludge plant are:

1. Volume of air applied.
2. Concentration of suspended solids in aeration tank.
3. Aeration period.
4. Rate of sludge return.
5. Condition of the sludge.

Operating data from several activated sludge plants are shown in Table 1.

These variable factors must be properly controlled according to local conditions and changed as necessary to meet seasonal variations and fluctuations in load. They depend upon each other and a change in one will generally require changes in some of the others.

Volume of Air Applied: The volume of air applied is important not only as far as treatment is concerned but also because it determines the cost for power. In diffused air plants, the air is used to keep the solids in suspension so as to obtain thorough mixing and to supply oxygen for the microscopic organisms. It is essential to maintain aerobic conditions throughout the system (aeration and final settling tanks) for

best operation. It is wasteful to use more than necessary and injurious to treatment to use less than the required amount.

The average amounts of air used vary from about 0.30 to 2.0 cu. ft. per gallon of sewage. These values depend upon the concentration of aeration solids, the aeration period and the strength of sewage.

TABLE 1.—*Activated Sludge Plant Operation Data*

Plant	Sewage Flow (M.g.d.)	Air		Suspended Solids Aeration Tank (P.p.m.)	Aeration Period (Hours)	Return Sludge		Sludge Index	
		Cu. Ft. per Gal.	Cu. Ft. per Pound of B.O.D. Removed			Per Cent of Sewage Flow	Suspended Solids (Per Cent)	Donaldson	Mohlman
Chicago, Calumet	82.4	0.35	500	2,860	4.0	22.4	1.55	1.93	52
Chicago, North Side	196.0	0.42	462	2,500	5.4	22.4	1.31	1.27	79
Cleveland, Easterly	91.3	1.10	1,420	2,240	6.6	20.9	1.11	1.35	74
Findlay, Ohio	2.295	0.69	840	1,420	5.5	25.9	0.51	0.66	151
Ft. Wayne, Ind.	17.6	0.99	835	2,320	8.6	27.0	0.97	0.90	111
Gary, Ind.	21.5	0.41	910	1,350	3.9	32.5	0.45	0.98	102
Jackson, Mich.	9.15	0.60	650	3,020	—	15.0	—	2.86	35
Marion, Ohio	3.76	0.62	907	3,000	4.0	31.9	1.08	1.75	57
Muskegon Hts., Mich.	1.18	0.47	345	900	6.3	41.1	0.43	1.0	100
New York, Wards Is.	184.0	0.57	470	1,770	4.5	45.0	0.48	0.59	170
Pasadena, Tri-City	9.63	1.73	1,450	1,100	6.9	12.0	0.67	0.53	189
Rockville Center, N. Y.	1.99	2.0	2,180	740	5.0	3.5	2.70	2.63	38
Springfield, Ill.	9.2	0.64	950	1,580	5.45	28.0	0.42	1.03	97

The air used is sometimes expressed in cu. ft. per pound of B.O.D. removed. This method of expression has the advantage of showing the work done or the efficiency of the use of the air. As shown in Table 1, values may range from about 350 to about 2,200 cu. ft. of air per pound of 5-day B.O.D. removed. In comparing data from various plants, it is important to note that economy in use of air may not be important at plants where air compressors are operated by sludge gas engines.

The amount of air used is generally controlled by determinations of dissolved oxygen from one or more points in the aeration or final tanks. Some operators determine the dissolved oxygen content at the inlet and midpoint as well as at the outlet end of the aeration tanks. Others control the air from samples taken in the final tanks. Generally the dissolved oxygen is lowest near the influent end of an aeration tank and it increases gradually to the effluent end. A dissolved oxygen content of 2.0 to 5.0 p.p.m. is generally required at the outlet end of the aeration tanks in order to maintain aerobic conditions throughout the tanks.

In the activated sludge process, the entire load of sewage is normally added to the return sludge in a single dose at the inlet end of the aeration tanks. Consequently, the demand for oxygen is very high there. This demand for oxygen decreases as the sewage passes through the tank, reaching a minimum at the outlet end. In order to meet this high initial demand for oxygen, it has been proposed to add

the largest amount of air at the inlet end and gradually decrease it toward the outlet. This method, called tapered aeration, is being used at a number of plants.

Gould has suggested that instead of tapering the air, adding the sewage to the returned sludge in steps would even out the demand for oxygen throughout the aeration tanks. In New York City, he has provided for the addition of sewage to the returned sludge at three points in the aeration tanks. This process is called "step aeration."

Concentration of Suspended Solids in Aeration Tanks: The control of the concentration of suspended solids in aeration tanks is one of the most important factors in operation. As shown in Table 1, the concentration varies considerably with the individual plant, ranging between 500 and 3,500 p.p.m., with values between 1,500 and 2,500 p.p.m. most common. There is no single optimum for all plants. In general, no more solids should be used than are needed to purify the sewage properly.

The concentration of suspended solids which should be maintained in the aeration tanks seems to be related to the volatile solids in the sewage. There is some evidence to show that if the percentage of volatile solids is high, the concentration of solids in the aeration tanks should be low since sludge with a high volatile content is bulkier and settles less readily than one with a high ash content and may therefore yield a poorer effluent. Sludge with a high percentage of volatile matter is apt to be more active biologically than one with low volatile solids, and if the total suspended solids in the aeration tanks are high, it may be difficult to maintain aerobic conditions, especially in the summer months. Conversely, with lower volatile solids, higher concentration of solids may be carried in the aeration tanks.

Within a plant, the concentration of solids may vary 500 to 1,000 p.p.m. from time to time. Sometimes this variation is intentional because of seasonal or special operating conditions. Sometimes, it is unintentional, as for example, a concentration of suspended solids, much higher than usual, may be caused by heavy storms or by the necessity of temporarily storing sludge in the system.

Aeration Period: The aeration period can usually be varied only within very narrow limits unless extra tank capacity is available. When several aeration tanks are in use, one or more of them may be removed from service in order to reduce the detention period in the others. In practice, the aeration period is most commonly 4 to 6 hours.

Long periods usually produce a high degree of purification with oxidation of nitrogen to nitrates. Since high nitrates stimulate the growth of algae and other aquatic plants, they may be undesirable in the outlet watercourse. With long aeration periods, however, the activated sludge process is less upset by shock loads and the plant is easier to operate. With short aeration periods, the process is more sensitive to sudden change and the plant is more difficult to operate.

Rate of Sludge Return: The rate of sludge return is usually expressed as a percentage of the sewage flow. For example, if the sew-

age flow is 10 m.g.d. and the return sludge rate is 25 per cent, the volume of return sludge would be 2.5 m.g.d. and the total volume passing through the aeration tank would be 12.5 m.g.d. Usually the rate varies from 20 to 45 per cent.

The concentration of solids in the aeration tank is controlled by the amount of excess sludge drawn off for disposal, or wasted. Within limits, the rate of sludge return is not usually important as a high rate means thin sludge returned and a low rate means a heavy sludge. It is the pounds of solids returned to the aeration tank rather than the volume which must be controlled.

It is very important, however, to keep the solids fresh and the return rate should be high enough to avoid stale sludge. Returning sludge at a rate higher than the scrapers can bring it to the sump may mean circulation of aeration liquor. At Wards Island, where excess sludge is concentrated in separate tanks, the final tanks are kept as free from settled sludge as possible. Final settling tanks should not be used for sludge storage.

Condition of the Sludge: The condition of the sludge which reflects the success of the operator in controlling the environment is generally determined by its appearance and odor, settling characteristics and by microscopic examinations.

Fresh, well conditioned activated sludge is brownish in color turning black as it becomes septic. It normally has a characteristic musty odor when fresh but becomes foul and sour when allowed to stand in the absence of air. The floc of good quality sludge is moderate in size and the water surrounding it on settling is clear and colorless.

The settling characteristics of sludge have considerable value in controlling operation and may be expressed in several ways. Theriault in 1920 called attention to the value of the "sludge ratio" as determined by dividing the parts per million of suspended solids in the aeration tank by the volume in milliliters occupied by the sludge after settling one liter of liquor for a period of 15 and 30 minutes. No single time was proposed and little or no practical use was made of the suggestion in the operation of activated sludge plants. Donaldson in 1931 proposed the "sludge index" for a practical routine test and computed it by dividing the percentage of aeration tank suspended solids by weight times 100 by the volume of sludge settled in 30 minutes, also expressed in per cent. Sludge index values above 1.0 were considered satisfactory for normal operation. Later experience has shown that some plants, such as Wards Island, may operate satisfactorily with an index as low as 0.50. In 1934, Mohlman proposed that the sludge index be defined as the volume in milliliters occupied by one gram of sludge after 30 minutes settling and calculated by dividing the volume of sludge in per cent after 30 minutes settling by the weight of suspended solids in per cent. With this index, values less than 100 are considered satisfactory. The Mohlman index can be converted into the Donaldson index by dividing into 100. It is immaterial which index

is used since all are based on the relation between the volume of settled sludge and the weight of suspended solids.

The index varies with the volatile solids content in such a way that the higher the volatile solids, the poorer the sludge index. No single value can be considered as critical for all plants but should be determined for each individual one. The use of the index is helpful in control of the aeration process because it indicates when trouble is approaching and gives the operator a feeling of security when the index consistently shows a well settling sludge.

The microscopic examination of activated sludge to determine the numbers and types of organisms is a valuable aid to plant control, especially where the condition of the sludge is variable. A compact floc with abundant stalked ciliates, few flagellates and very few filamentous bacteria indicates a good sludge. Diffuse floc, many flagellates and amoebae, few ciliates and a preponderance of filamentous forms means a poor settling sludge. The frequency of examination will depend upon the individual plant. When the sludge appears to be well conditioned, an occasional examination is sufficient, but when there is reason to suspect trouble, daily examinations may be necessary.

Sampling

In order to control the process and determine accurately the operating results, as many samples as practicable should be collected at regular intervals throughout the 24 hours of the day. The purpose of collection of samples of sewages and effluents is to obtain a representative sample of the liquid for use in making a laboratory examination. The great variety of conditions under which collections must be made make it impossible to set up a fixed procedure.

The standard method comprises collection of composite samples over two 12- or one 24-hour period. Individual portions should be collected at least every hour and mixed at the end of the sampling period or combined in a single bottle as collected. A final volume of 2 to 3 liters is generally sufficient for sewages and effluents. It is desirable to combine individual samples in volumes proportional to the volume of flow.

All samples should be analyzed as soon as possible after collection and kept in a cooler until analyzed.

Grab samples, except for the dissolved oxygen determinations and for bacteriological examination, are not satisfactory.

Routine Tests

Certain routine tests are particularly helpful in controlling operation. Determinations of dissolved oxygen and suspended solids in the aeration tank are used to control the amount of air used and to maintain the proper suspended solids concentration. Settling tests on aeration tank effluents are needed with the suspended solids to calculate the sludge index. Centrifuge tests are used as a rapid check on

the concentration of sludge to control wasting of sludge. The depth of sludge or sludge blanket in concentration tanks is also a valuable aid in controlling the wasting of sludge. The use of the microscopic examination has already been mentioned. Along the coast, the determination of chlorides in the raw sewage is helpful in ascertaining the leakage of tide water into the sewerage system. Wide variations in pH values indicate discharges of industrial wastes.

Routine laboratory analyses useful in plant operation are as follows:

- Raw and settled sewage
  - Biochemical oxygen demand
  - Suspended solids
  - Volatile suspended solids
  - Organic nitrogen
  - Ammonia nitrogen
  - Settleable solids
  - pH
  - Chlorides
- Activated sludge effluent
  - Biochemical oxygen demand
  - Suspended solids
  - Volatile suspended solids
  - Organic nitrogen
  - Ammonia nitrogen
  - Nitrate nitrogen
  - Nitrite nitrogen
  - Dissolved oxygen
- Aeration tank effluent
  - Suspended solids
  - Settleable solids
  - Dissolved oxygen
- Return sludge
  - Suspended solids
- Primary and waste activated sludge
  - Total solids
  - Volatile solids

Most of the other tests, such as the suspended solids, B.O.D. and nitrogen determinations, are not used directly in plant control as the time required to make them is too long. They are extremely useful in giving an over-all picture of the efficiency of treatment. The suspended solids and B.O.D. determinations are particularly valuable in showing the progress of purification through the plant and the work done by the individual units.

Disposal of Excess Activated Sludge

Because of the high moisture content of excess activated sludge, it is necessary to concentrate it before disposal. A common method of

thickening it is to return it to the raw sewage so that the activated sludge solids are removed with the sewage solids in the primary settling tanks. Theoretically, the activated sludge floc should help clarify the sewage and cause better removal of suspended solids in the primary tanks. If the excess sludge is light and the primary settling period short, however, there is some danger of poorer settling portions passing through the primary settling tanks and tending to build up in the aeration system with a consequent deterioration in the quality of the sludge. When the excess sludge settles well, discharge of the sludge to the primary tanks at a low uniform rate is reasonably satisfactory if the sludge is removed frequently from the primary tanks. Success probably depends largely upon the volatile solids content of the sludge. Low volatile solids mean rapid settling and satisfactory removal of the sludge in the primary tanks. High volatile solids mean poor settling and passage of sludge through to the aeration tanks.

Separate concentration tanks are used at many activated sludge plants to thicken either aeration tank effluent or return sludge. Some operators believe that the fresh aeration tank effluent concentrates better than the stale return sludge. In any event, the effectiveness of the concentration will depend to a considerable extent upon the percentage of volatile solids.

The concentrated sludge may be disposed of in many ways, such as: digested, dried and used for fertilizer; dried and incinerated or barged to sea. Pearse reported that about 90 per cent of the activated sludge plants were disposing of the excess activated sludge in separate sludge digesters.

Purification Obtained

An important characteristic of the activated sludge process is the high degree of purification which may be obtained. So much of the suspended solids and colloids may be removed that under ordinary circumstances, the settled effluent will be clear and contain but little suspended matter. The removal of suspended matter and B.O.D. varies from 85 to 97 per cent. As shown in Table 2, the average removal of suspended solids and B.O.D. from twelve representative plants averaged was more than 90 per cent.

At Wards Island, the average removal of bacteria growing on agar at 37° C. has been 98 per cent and of members of the *coli-aerogenes* group, 99 per cent. The number of bacteria remaining, however, usually make chlorination necessary for disinfection where the effluent of an activated sludge plant is discharged in the vicinity of bathing beaches or shellfish layings.

Sludge Bulking

Good quality activated sludge settles rapidly and a tendency toward slower settling and a poorer sludge index is an early sign of deteriorating sludge quality. As the floc particles increase in size and decrease

in density, the depth of sludge or the sludge blanket in the final settling tanks increases until natural currents carry the solids over the weirs with the effluent. This bulking or swelling of the sludge in volume is associated with loss of sludge activity and is characterized by a low settling rate and by a very poor sludge index. Filamentous growths such as *Sphaerotilus* are usually present in the stringy, deflocculated

TABLE 2.—*Removal of B.O.D. and Suspended Solids by Activated Sludge Treatment*
(Results in p.p.m.)

Plant	Suspended Solids				B.O.D.			
	Raw Sewage	Settled Sewage	Final Effluent	Per Cent Removal	Raw Sewage	Settled Sewage	Final Effluent	Per Cent Removal
Chicago, Calumet	129	—	12	92	92	—	9	90
Chicago, North Side	139	—	10	93	115	—	6	95
Cleveland, Easterly	239	165	12	95	148	106	13	91
Findlay, Ohio	427	90	11	97	405	121	21	95
Gary, Ind.	302	95	10	97	129	63	9	93
Jackson, Mich.	191	141	17	91	122	118	7	94
Marion, Ohio	241	104	12	95	145	98	9	94
Muskegon Hts., Mich.	305	134	69	77	357	193	52	86
New York, Wards Is.	204	—	20	90	167	—	14	91
Pasadena, Tri-City	303	—	27	91	149	—	13	91
Rockville Center, N. Y.	284	146	25	91	288	160	41	86
Springfield, Ill.	132	81	8	94	103	74	8	92

sludge. These organisms, however, are probably symptoms of a sick sludge, rather than a cause. Many causes have been given for bulking but the most important are too high or too low concentration of solids in the aeration tanks, insufficient air, overloading or very high volatile content of the suspended solids.

If the concentration of suspended solids is permitted to increase to such a point that aerobic conditions are not maintained throughout the aeration tanks, bulking may occur. Insufficient air is an important cause. If the concentration of solids decreases to about 500 to 800 p.p.m., a critical range is reached where very poor settling results. A further decrease in aeration tank solids yields a sludge which settles very rapidly.

Activated sludge may become sick by being overloaded, that is, by adsorbing more decomposable organic matter than there is oxygen available for its oxidation. A good sludge may deteriorate by the addition of an abnormally strong sewage and will be overpowered if overloading is long continued. Overloading is often caused by large amounts of industrial wastes.

High volatile solids content of the aeration solids appears to be a frequent cause of bulking, particularly in the summer. Relief is commonly obtained by a rain where the sewage is collected in a combined system.

The correction of bulking seems to depend upon a restoration of balance between oxygen demand and supply. This may be done by: (1) increasing the air supply; (2) adjusting the suspended solids in the aeration tanks, reducing them if they are too high and increasing them if necessary; (3) decreasing the sludge activity by the addition of chlorine; (4) by-passing part of the sewage flow if possible and (5) evening out the flow of industrial waste if overloading is caused by intermittent discharge.

Chlorination of returned sludge has been successful in combatting bulking at a number of plants. The amount of chlorine used depends upon the concentration of solids and at Lima, Ohio, the dosage averaged 8.5 p.p.m. for each per cent of suspended solids in the returned sludge. In some cases, treatment with chlorine has not been successful.

Rising Sludge

Another operating problem is the occasional rising of large masses of sludge to the surface of final settling tanks. This may occur when nitrification is high and in the absence of oxygen, the nitrates in the sludge blanket are decomposed to form nitrogen gas. The bubbles of gas will carry sludge masses to the surface. This condition is quickly corrected by reducing the amount of air applied. Increasing the sewage load or reducing the aeration tank solids in the unit causing the trouble is said to be helpful.

Rising sludge may also occur as the very dense sludge in a final settling tank or concentration tank becomes septic. The gases formed become entrained in the sludge and carry it to the surface. The septic sludge must be removed and the sludge blanket kept low to prevent septicity. Failure of the sludge collectors to keep the tank bottom clean during warm weather is a common cause of this trouble.

Modifications of the Activated Sludge Process

By varying the air supply, the aeration period and the amount of returned solids, any degree of purification between sedimentation and conventional activated sludge can be obtained. For partial treatment, low air supply and small tank capacity are sufficient. Greater air supply and tank capacities will permit more complete treatment. Where conditions warrant, a high rate activated sludge offers a means for substantial economies in construction and operating costs. It is emphasized, however, that the type of treatment depends upon the degree of purification required. Where the highest degree of purification is necessary, conventional activated sludge should be used.

To illustrate the effect of varying some of the factors in the activated sludge process, data from several plants are presented in Table 3.

Starting with plain aeration at Indianapolis, 59 per cent removal of B.O.D. was obtained in 6.4 hours. With very low aeration tank solids and a short aeration period at Jamaica, 70 per cent B.O.D. was removed and by increasing the solids, a slightly better effluent was pro-

duced. At Rockville Center, longer aeration with moderately low solids yielded 86 per cent removal of B.O.D. and at Bowery Bay, a short aeration period with high suspended solids produced an effluent of the same quality expected from the conventional activated sludge plant.

TABLE 3.—*Modifications of the Activated Sewage Process*

Plant	Date	Aeration Period (Hours)	Air (Cu. Ft. per Gal.)	Sludge Returned (Per Cent)	Aeration Tank Solids (P.p.m.)	B.O.D. Removal (Per Cent)
Indianapolis.....	1942	6.4	0.49	0.0	156*	59
New York, Jamaica....	Sept., 1944	2.28	0.29	16.0	365	70
New York, Jamaica....	June–Aug., 1944	2.35	0.32	27.0	630	71
Rockville Center, N. Y..	1942	5.03	2.0	3.5	740	86
New York, Bowery Bay	1942–43	2.6	0.59	46.0	1800	90
Chicago, North Side...	1936	3.0	0.37	21.7	—	91

* Suspended solids in settled sewage.

In varying from the conventional method of operation, the activated sludge process becomes more sensitive to shock and fluctuations of load and flow, and requires much more careful supervision.

If any conclusion can be drawn from a paper of this kind, it is that because of factors such as differences in characteristics of the sewage and variations in flow, each activated sludge plant is different from any other. No arbitrary rules for plant operation can be safely set up beforehand and many of the variables can be fixed only by experience.

Mention should be made of two excellent reviews of activated sludge operation. The comprehensive report of the Committee on Sewage Disposal of the American Public Health Association, of which Langdon Pearse was Chairman, was published in THIS JOURNAL, **14**, 1, 3 (1942). W. H. Wisely has presented additional data in a paper published in THIS JOURNAL, **15**, 5, 909 (1943). Some of the information presented in this paper has been taken from these sources.

THE DAILY LOG

BY WALTER A. SPERRY

Superintendent, Aurora (Illinois) Sanitary District

September 1—What a relief! The 14th Annual Report of the Aurora Sanitary District for the calendar year 1944 has been compiled, written, printed, gathered, bound and is in the mail. We are justifiably proud of the fourteen sets of monthly data sheets and of the annual which have been bound and hung on a hook in the office. They are a mine of information about the daily deeds and misdeeds of fourteen years. A careful review of every plant's operation history is an obligation on the part of every superintendent

as a record of stewardship, a reference file and as a contribution to the profession.

September 10—Another surprise day. Unannounced, Mr. J. Donald Walker of the American Well Works came out with Mr. S. F. Wang, Sanitary Engineer of the National Department of Public Health, China, to see the plant and talk "shop." Mr. Wang is one of a group of sanitary engineers sent to the United States for an observational tour. After lunch we decided to visit a few plants "up-river" in his honor. During the afternoon we visited ten plants, turning back after a brief visit with Floyd Johnston, Superintendent of the Elgin Sanitary District, 25 miles north of Aurora. The payoff came while looking at the effluent of the chemical precipitation type of sewage treatment plant of the Campana Company at Batavia, Ill., makers of "Italian Balm" and other cosmetics. The effluent was not only good looking but beautifully perfumed as well! Now there's an idea, if not a prophecy!

September 14—As sure as death and taxes is the annual visit of the compensation insurance inspector. This time the superintendent was downtown and Assistant Willard did the honors. For the past year or two he has found nothing to be critical about but this year he spied an extension ladder without rubber soled feet. It was a sensible idea and they will be applied.

September 18—More river pollution trouble. In the July, 1945, Log appeared a story of a forging plant with a small waste of heavy oil. The use of a straw filter was suggested but priorities delayed the building of an adequate unit. The temporary barrel arrangement was not managed well and a small amount of oil escaped. Then one day the engineer of the local power company came in to ask what we knew about oil pollution on the river, adding that their big turbine condensers were filmed with oil which had not only seriously impaired their efficiency but that the expensive task of cleaning had to be much more frequent. It was both disturbing and interesting to learn the serious effects of what we knew to be very small amounts of oil. In the meantime, not knowing of our work on the problem, they had suggested to their customer the use of a centrifuge, thinking to conserve the waste oil. This remedy failed as we predicted. Subsequently, after a joint survey of the creek and river, the forging company thoroughly cleaned the creek of brush, debris and small oil pools. Your Logger was embarrassed by being unable to think of a more effective way of lifting light oil pools from the water surface than by using cheese cloth on a wire frame. We would welcome suggestions.

September 20—For the past fifteen years we have used a five-gallon copper retort still with worm for distilling water, until corrosion and scale destroyed it. Today we have a new Stokes gas-fired still with a Pyrex glass dome. It looks so unlike a bootleggers outfit to the layman that all the "wisecracking" from visitors over the years about our private stock of "moonshine" will cease. To a teetotaler this at times was embarrassing.

September 22—A "grape vine" post card from Fred Simms, Supt. of the DeKalb Sanitary District announced that Miles Lamb, City Engineer and Super-

intendent of Water and Sewage for the city of Belvidere, Ill., has resigned to enter the service of the Chicago Pump Co., to be in charge of service, new construction and new work. Miles was a popular leader among Northern Illinois operators and we shall miss him. We wish him luck in his new venture.

September 23—Today is Sunday. Despite 37 years as a public servant, and most of the time with Sunday duties, it is still a bit peeving to be called at home in the middle of the afternoon or after supper just as one starts for a show, and be asked to come and make a sewer inspection. Being a good servant, one grumbles and goes. This time we caught a near criminal. He had called for his measurements, which are readily given, but forgot to come later for the little formalities of application, bond and permit to say nothing of the $40 fee required! We collected his money at once, then checked his measurements and set the day, hour and minute for his appearance at the office to square himself. He came in on time and left feeling we were not too tough after all.

October 6—Only those who have read "Party Line" can appreciate all the kinds of interruption the telephone can make. Today and before noon we came, mostly out of breath, from distant parts of the plant to discuss (a) septic tanks and open-joint tile drains for city lots, with a local bank president, (b) to advise with the local C. B. & Q. R. R. chemist on the best way to get small traces of oil out of distilled water, (c) to give an opinion to the County Farm Advisor as to whether a septic tank effluent running in an open ditch through a hog lot would make pigs sick, (d) to give a report, as trustee of an old folks home, on the status of four small contracts for a board meeting we were too busy to attend, (e) to discuss the deferment status of an employee with his draft board, (f) to advise on the overhaul of the plant power mower and (g) to receive instructions from friend wife about bringing some vegetables home. Phone quiet all afternoon and we got some work done.

October 8—Another worried citizen in today to ask about his septic tank. Some think we have a magic fluid that will clean them without work. Some want to know how much yeast it takes to start them. Some ask if they must not exclude all dishwater, bath water and laundry water. Nearly all of them have some form of round, deep, iron tanks with wretchedly designed baffles that clog and give trouble. Yesterday we were asked how to build a good privy. We have accumulated a lot of good advice and kindly council for these unfortunates without good sewer facilities but the best part of it is to have on hand a good supply of your state department of health bulletins describing just how to build good septic tanks and privies and advising as to the wisdom of their use. You will find that folks are no end grateful.

October 13—A busy Aurora factory superintendent, acting as a Boy Scout leader, here this Saturday afternoon with his troop. We did our part by giving them a thorough inspection trip and description of the plant.

October 15—A $50,000 tax check in the mail this morning. Twenty thousand dollars of this check were deposited directly to the pay roll account. No pay day worries for a while!

October 19—This day we finished retubing the exhaust gas heat exchanger. The story of Aurora's experience may be helpful to other engine users. The Aurora heat exchanger is a two-pass vertical heater with 32 1¼-in. tubes about ten feet long. The original tubes were seamless steel rolled in place and they lasted about 3½ years. The heater was retubed in 1939 with Byers wrought iron pipe, welded to the heads. So far as practical the temperature was kept at or above 130° F.—the dew point—to check corrosion. These tubes lasted five and a half years. This summer it was agaín retubed with Byers wrought iron pipe rolled in and not welded as before. Due to the difficulty of burning out the old tubes the heads were destroyed and new heads were made of 1-inch plate as before. The welder pointed out that whereas the welding method caught only the ends of the tubes they would start to leak as soon as corrosion destroyed the welding. If the tubes were rolled in they would be tight the full thickness of the head plates and considerably more corrosion could occur before failure of the heater. In addition, the rolling method would never again destroy the head plates. He confidently predicted a possible seven years of life for the rolled job. About eight of the tubes split at the seams for a short distance back from the ends and had to be removed, the seam reinforced, ground down and then re-rolled. The thicker pipe wall and the type of metal both seem more desirable than the steel tube until, now that the war is over, we can get some special corrosion resistant metals.

FIGURE 1.—An improvised suction hose repair and a novel solution of the vortex problem.

October 22—Figure 1 illustrates two items of interest. While dewatering a clarifier tank the 4-inch rubber suction hose broke open due to old age. We had no other hose and had to finish the job and the inspiration born out of the calamity of the moment worked. A roll of friction tape, some splints hastily split from a board, some wire, a pair of pliers and twenty minutes did the trick.

The 10-inch board wired to the top of the end of the hose and projecting some twelve inches beyond was another quick idea that worked perfectly to kill the vortex effect and enable us to pump the tank nearly dry. Without the board the pump would have lost its suction when the water was still some four or six inches above the top of the hose. With the board in place the water was pumped down to nearly an inch below the board before the pump lost its suction and the engine began to race. A patent has been applied for but no one will be prosecuted who can use the idea!

Figure 2 is included to allay the fears of any reader who is concerned about the object pictured in your Logger's mouth in Figure 1. The object is a pipe which was presented to your Logger by his son Walter, Jr., with a broad grin and the comment that it was very appropriate to our profession; the bowl of the pipe is a model of a highly essential plumbing fixture, equipped with a hinged lid.

FIGURE 2.—Operator's Utopia—a pipe, a moment of leisure and "The Operator's Corner."

October 26—Two digesters are blowing their seals again today and, sure enough, our suspicions were confirmed. The iron and sulfur scale has caught up with us again and accumulated sufficiently to cause back pressure in our new pipe lines. Not a new experience. Two lines of 2-inch pipe about 100 feet long had to be opened, flushed and well hammered to free the scale. This is the beginning of their end in a few years. The job has to be done every eight or ten months and spoils two days.

October 29—Certainly one of the worst nuisance problems about the grounds of many sewage plants is weeds. "The Daily Log" would welcome tried and proven suggestions from its readers to be passed along to others. We are beginning this discussion with a few notes by M. M. Talbot, Senior Botanist on Weed Investigation, U. S. Dept. of Agriculture. He states that out of the many remedies tried out as herbicides, four types have proved fairly effective. These are the chlorates, oils, common salt and the soluble arsenicals. To this list may now be added ammonium sulfamate, cyanamide and the kerosene torch, which we hope to discuss later.

The chlorates are highly effective but must be used with caution due to the well known danger of spontaneous combustion following drying on cloths and friction. The chlorates are applied at the rate of three pounds per square rod.

Crude carbolic acid is one of the most effective agents of the oil group and is applied at rates of two to three gallons per square rod.

Common salt and calcium chloride have long been used as weed killers. Salt is applied at the rate of 35 to 65 lb. per square rod and calcium chloride at the rate of 60 lb. per square rod.

The soluble arsenicals are to be used with caution due to their poisonous nature but are ten times more effective than salt. Sodium arsenite is applied at the rate of forty gallons per square rod when containing four pounds of arsenic salt. More about this later.

THE GADGET DEPARTMENT

THREE USEFUL OPERATION SUGGESTIONS

By David Bartholomew

Chief Operator, Pratt and Whitney Sewage Treatment Plant, Southington, Conn.

Air Cushion at Chlorinator

Although it is not a new idea, an air cushion chamber on the high pressure water line of a chlorinator (Figure 1) may save considerable trouble and expense in connection with chlorinator operation and main-

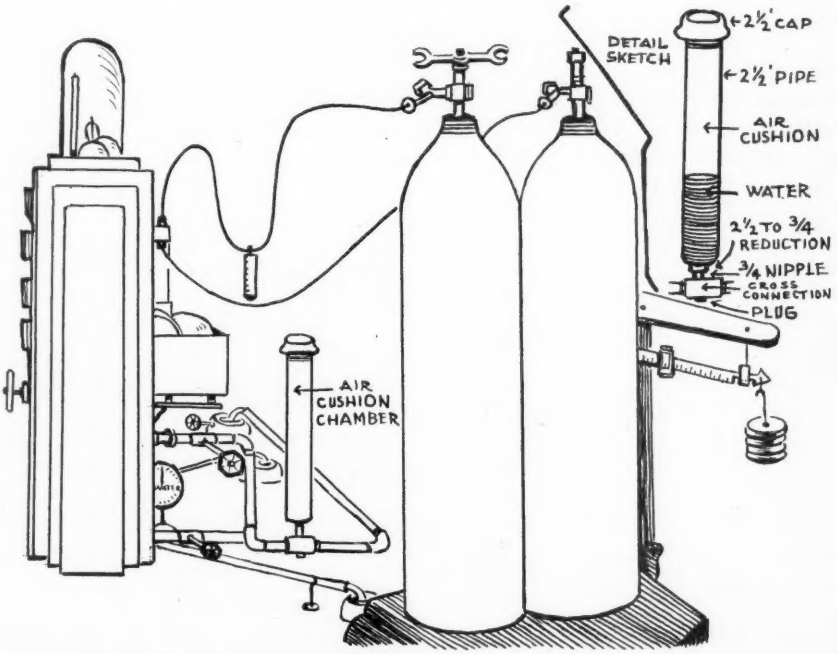

Figure 1.—Air cushion for control of surge pressures at chlorinator.

tenance. This device solved the problem of controlling the surges of pressure which were constantly disrupting the adjustment of chlorinator valves and gauges.

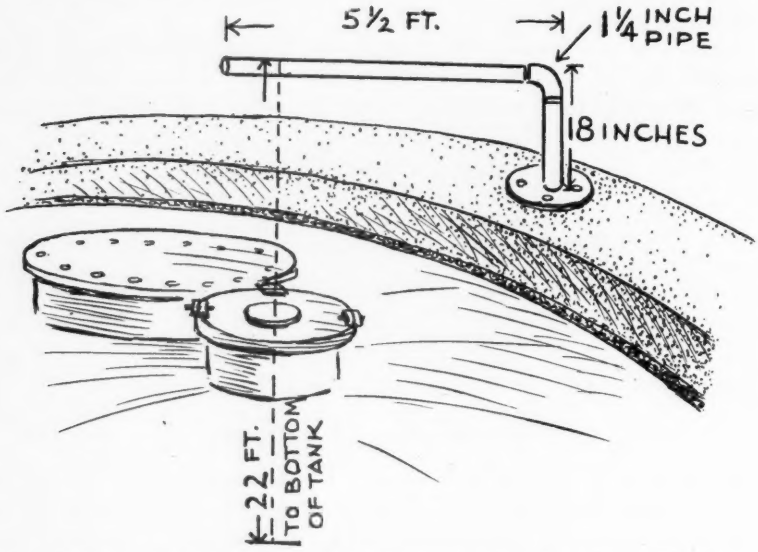

FIGURE 2.—Fixed base for depth measurements at floating cover digesters.

The cushion indicated is made of 2½-in. pipe, 26 in. long, with a cap at the top and a 2½-in. by ¾-in. reducer at the connected end. It is connected to the high pressure line at a ¾-in. cross, with a plug or valve at the bottom to provide drainage and for use when it is necessary to admit the air required for maintenance of the cushion.

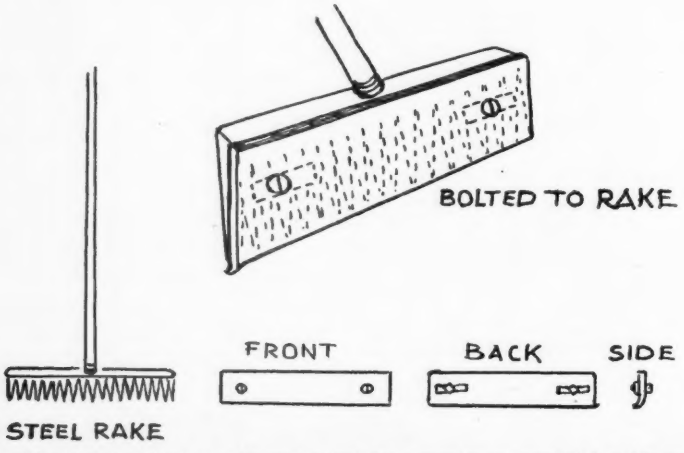

FIGURE 3.—Metal plate bolted to rake makes tool for removing accumulated solids and weeds at sand filters or sludge beds.

Base for Depth Measurements at Floating Cover Digesters

To expedite the measurement of the depth at which samples are taken at a floating cover digester, the arrangement shown in Figure 2 has proved highly successful. Before this device was installed, it was necessary to drop the sampler to the bottom (which was actually a point on the slope of the conical hopper, 2½ ft. above the deepest point) and then raise the sampler to the desired point. The swing-pipe benchmark now gives a direct depth measurement.

Scum and Weed Rake

The simple gadget shown in Figure 3, consisting only of a sheet metal plate bolted to an ordinary garden rake, has been extremely useful for removing surface solids accumulations and small weeds at sand filters and sludge drying beds. The plate is made of 14-gauge sheet, with the bottom edge bent back slightly and sharpened so as to catch weeds.

TIPS AND QUIPS

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Inklings from Indianapolis, where the Indiana Sewage Works Assn. held an abbreviated one-day meeting on August 17 . . . a fitting climax to "Stream Improvement Week," so proclaimed by Gov. Gates . . . a progress report on the activities and aims of the State Stream Pollution Control Board, by C. K. Calvert, a member of the Board . . . which revealed that abatement orders have been issued to 41 municipalities and six industries . . . presentation of the Annual Award of Merit to Supt. W. W. Mathews of Gary by Awards Chairman T. J. Burrin, this honor being based on operation records, public relations activity and research and development accomplishment . . . a trip through the Indianapolis sewage treatment plant, the first in almost ten years, with an opportunity to chat with Supt. W. H. Frazier and Asst. Supt. Dwight Bender . . . the news that Jo Quinn, Jr., energetic Acting Chief Engineer of the Division of Environmental Sanitation, State Board of Health, is leaving the service of the state for other employment, in which our best wishes are extended . . . and a pleasant drive home to close a good day.

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From C. O. Baetz, Sanitary Engineer, R. and U. Section, Ninth Service Command (formerly superintendent of the Appleton, Wis., plant), comes this tip on sludge pumping. The device and piping arrangement shown in Figure 1 is in use at the plant serving the Dewitt General Hospital and operated by Mel Wise, and is employed in several military installations in the West in which centrifugal sludge pumps are used.

The arrangement is simply a 1½-inch by-pass from the discharge to the suction of the pump, in which a sight glass and sampling cock are placed. An angle valve is shown above the sight glass and a gate valve (not pictured) is located between the sampling cock and suction line

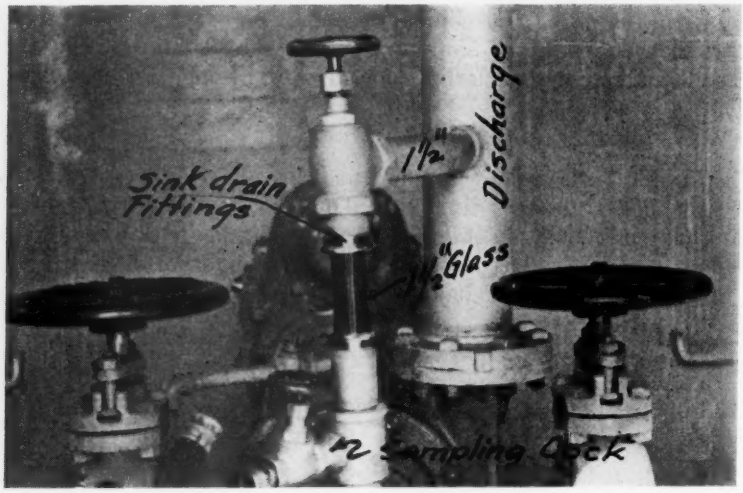

FIGURE 1.—By-pass, sight glass and sampler for use at centrifugal sludge pumps.

connection. The by-pass is useful for relieving suction difficulties resulting from gas accumulation; the sight glass enables the operator to observe whether or not pumpage is actually taking place.

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Bowling Green, Ohio, through recent action of the City Council, has inaugurated a plan which should eliminate political interference with its municipal utilities. The municipal sewage works, water works and electric services have all been placed under the direction of a Utilities Board, which Board comprises three civic-minded business men appointed for three-year terms. Members of the Board are appointed by the Mayor but the terms are so arranged that only one term expires during the two-year period of office of any Mayor. Boyd Case is the present Manager of Utilities and L. B. Barnes is Superintendent of Sewage Treatment.

Orchids to the Council of Bowling Green for a long step in the right direction!

• • •

Vortex difficulties at the entrance to pump suction lines are a common vexation in sewage works. Logger Walt Sperry describes a method of solution in regard to suction hoses in the "Daily Log" column of this issue; another suggestion applicable to wet wells is gleaned

from the March–April, 1945, issue of *Goulds News,* house organ of Goulds Pumps, Inc.

The device is illustrated in Figure 2. Instructions for making the baffle follow:

"A simple welded baffle, which can be made in any maintenance shop from scrap sheet steel, will usually help smooth out the vortex. Its size, of course, will depend upon the suction pipe diameter and the depth of liquid in the tank. This inexpensive fixture is well worth trying where trouble has been experienced from the above mentioned cause. Although the application illustrated shows the baffle for use where the tank is above the pump, the same principle can be applied in other types of installations where a vortex forms at the suction pipe entrance.''

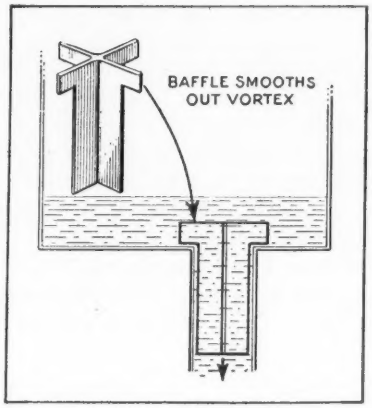

FIGURE 2.—Baffle for eliminating vortex at pump suction entrance.

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Flammable solvents as a fire hazard are given special attention in a warning issued recently by the Safety Research Institute. The frequent presence of such compounds in sewage justifies application of the following recommended practices at manholes, wet wells and screen chambers of sewage works:

"Every year, flammable solvents, such as gasoline, naptha, benzene, and acetone, cause fires and explosions that kill or injure hundreds of persons and destroy property worth millions of dollars in American business establishments. To ensure safety, therefore, adequate protection from these hazards must be provided wherever flammable solvents are employed.

"Even when used in small quantities, flammable solvents require careful handling. They should be kept in approved safety cans and applied where there is no danger of ignition from flames, mechanical or electric sparks, or high temperatures due to fire or friction. Smoking in the area of application should be prohibited.

"To prevent disastrous explosions, the concentration of solvent vapor in the atmosphere must be kept below the lower explosive limit by using equipment that minimizes the escape of vapor into the air and by supplying a sufficient amount of fresh air by means of natural or mechanical ventilation. In practice, the vapor content of the workroom air should be kept below the "maximum allowable concentration for continuous exposure," which is basic protection from both toxicity and explosion.

"But good general ventilation does not eliminate the localized fire hazards created by volatile flammable solvents. Special precautions must be taken to prevent the ignition of spills, creeping vapors, which may travel 100 feet or more from the point of origin, vapors collected in low places, such as pits or basements, and the explosive vapor-air mixtures that remain in containers emptied of solvents.

"In removing all possible sources of ignition from areas where flammable solvents are being handled, enclosed explosion-proof electrical equipment should be installed in accordance with the National Electrical Code; non-sparking bronze tools should be used; and workers should be provided with shoes made without nails.

"For extinguishing fires in flammable solvents, an ample number of portable fire extinguishers, bearing the approval of the Underwriters' and Factory Mutual Laboratories, should be provided. Types suitable for use on fires in flammable liquids include foam, vaporizing liquid, carbon dioxide, loaded stream, and dry powder."

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Sewer ordinances controlling the usage of public sewerage systems are again brought to mind by the foregoing item. The most direct method of combatting flammable solvent hazards in sewage works is to prevent the discharge of such substances to the sewers—a prerequisite to which is a complete and practical ordinance. Rigid enforcement of the ordinance will eliminate the hazard at the source.

Requests for reference material to be used in developing sewer usage ordinances continue to outnumber all other types of inquiries received at Federation headquarters. Sample copies of workable ordinances are sorely needed for this purpose and an effort is being made to gather a substantial file of them.

Even though the ordinance used in your municipality may not be all that is desired, please have the City Clerk send us a copy of it. Many thanks!

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A busman's holiday took us recently to three Northern Indiana plants on a most instructive tour. A brief stop at Gary found Supt. W. W. Mathews rejoicing in the renewal of sludge hauling by users of small quantities, as a result of the abandonment of gasoline rationing. His confidence in his assistant and operation crew was such that he felt no qualms at leaving them to complete a major repair of the grit chamber equipment while he accompanied us on visits to the plants at East Chicago and Hammond. We did secure one tip, however, before proceeding—the suggestion that undue wear at the gears of pressure gauges on the discharge side of air compressors (where vibration is severe) can be eliminated by shutting the valve at the base of the gauge except when readings are desired.

A pause at East Chicago found Supt. Steve Levan writhing in the throes of hay fever and the task of operating the new Guggenhiem process plant with two-thirds of an operation crew. Diffuser clogging seen at its worst, a five-day cleaning cycle being required. Another case where available sludge lagoon area is a boon; the present personnel is inadequate to operate the vacuum filters and incinerator. And plenty of other troubles, too!

At Hammond, Supt. Carl Carpenter was calmly contemplating his cash balance, with nothing more to worry him than the annual budget. Everything under control here, although a large quantity of acid spilled to the sewers at a local industry wrought havoc with the activated sludge early in the summer. The next maintenance project will be replacement of the brass plows of the final clarifier equipment. There was double pleasure in visiting this modern plant, particularly notable for its complete instrumentation and controls, when Supt. Carpenter promised us an article for the *Corner* on his experience in purging a pressure type gas storage unit!

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Sensitivity of the activated sludge process to upset, contended by many to be a primary disadvantage, is belied by experience at the Mogden Works in England, as related by C. B. Townend elsewhere in this issue. Located in one of the most heavily bombed areas of all England and subjected to a nightly shower of all kinds of bombs, shell splinters, etc., there is real drama in Mr. Townend's statement "yet never did the plant fail to produce a first class effluent from the whole of the sewage received, nor was any process interrupted for the shortest length of time."

At the moment, the Mogden plant can probably boast of having the most highly volatile sludge in the world in the digesters which "are operating today with six unrecovered explosive incendiaries" buried in their contents. Should these units happen to erupt vigorously one of these days, it will undoubtedly *not* be due to something that Londoners "et"!

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Editorials

THE ACTIVATED SLUDGE PROCESS

After 32 years of application, the activated sludge process of sewage treatment continues to receive intense study by plant operators and research investigators. This issue of the *Journal* is indicative of such interest, containing no less than six outstanding contributions concerning activated sludge treatment and constituting a notable reference on the subject. Four of these papers were to have been included in the technical program of the 1945 convention, which was to have featured the activated sludge process as its "theme."

When it is remembered that hundreds of technical articles have been published on the subject of activated sludge, it seems a bit surprising that new facts and discoveries continue to be forthcoming. One wonders at the impressively successful record of experience with the process as fundamental revelations continue to appear at this late date, proving that there is much more knowledge to be gained before the ultimate potentialities of the process are fully realized. Activated sludge treatment has been proved by its efficient and economical service in plants of very large to moderate size; the recent development of new and improved sludge gas engines will probably favor the adaptability of the process to smaller works in the future because of the possible reduction or complete elimination of purchased power. The worst statement that can be said against the process is that it requires careful and intelligent operation control and this, in fact, is not a disadvantage. The most unfavorable experience with activated sludge plants has been in very small installations where little or no operation supervision whatever has been afforded—a condition which would handicap any type of treatment.

On the black side of the ledger, the activated sludge process offers favorable construction costs, minimum area requirements, relative freedom from odors, a high degree of treatment, a waste sludge of high fertilizer value and, in large plants or smaller ones in which power is developed from digester gas, economy of operation. On the red side there is the high moisture content of the waste sludge, complicating treatment and disposal; the limitations in handling shock loads and overloads; lack of resistance to toxic substances (inherently troublesome in any biological process) and the requirement of closer operation control than other methods of secondary treatment. The shortcomings listed are receiving the brunt of the onslaught by researchers, to which the prolific and productive current literature will bear witness.

Lest their be accusations from the many exponents of the rugged trickling filter that this sturdy oxidation device is being subordinated, it is hastily pointed out that there is ample opportunity for the applica-

tion of both methods of secondary treatment, according to the respective merits of each. What is more, one of the chief products of wartime experience has been the knowledge gained from the observation of military sewage treatment plants incorporating both the activated sludge process and trickling filters. It is very likely that the advantages of both methods of treatment will be secured in many new and enlarged plants by the employment of such combinations to effect treatment in stages. This is a logical solution to problems involving the treatment of concentrated sewage and may result in the acceptance of stronger industrial wastes for treatment with sewage in municipal plants than have been taken in the past.

SLOW DOWN—PLANNING AND CONSTRUCTION AHEAD!

The timely note sounded by Benjamin Eisner in his paper "Better Sewers," as published in this issue, is a pertinent reminder that some undesirable practices have crept upon us in recent years. Mr. Eisner refers to the need for greater care and better supervision in construction; his caution signal might well be extended to earlier stages in the sewage works project, viz., planning and design.

With the onset of the public works therapy as a cure for the depression of a decade ago, a new element—speed—was injected into the normal routine of project development. Deadlines were set for filing of applications, preparation of plans and specifications, letting of contracts and completion of construction. As a result, adequate preliminary study, thorough design and good workmanship in construction gave way to the calendar in many instances.

Then came the war and an even greater acceleration of project development than had been known before, and for good reason. Some amazing jobs were completed in unbelievably short times but the results in many cases were not too satisfactory. Subsequent corrective construction was a frequent necessity.

We are now confronted with a sizable program of sewage works construction and, at the moment, there seems to be no real justification for time limits to complicate procedures. Certainly, a few weeks or months are of no great consequence when public service for twenty to sixty years hence is at stake. There will be an understandable desire on the part of consultants and contractors to garner a maximum share of the yield from the anticipated golden era but this tendency toward haste will be offset by the pride of professional accomplishment and workmanship that characterized this field before speed became the essence of activity during the days of PWA and the war.

W. H. W.

Proceedings of Member Associations

NEW ENGLAND SEWAGE WORKS ASSOCIATION

Sixteenth Annual Meeting

Springfield, Massachusetts, September 12, 1945

The Sixteenth Annual Meeting of the New England Sewage Works Association was held September 12, 1945, at the Hotel Kimball in Springfield, Massachusetts, with 112 members and guests attending. President Frank L. Flood presided.

The technical session included the following papers and discussions:

"Use of Effluent Water in Sewage Treatment Plants," by Robert Burrell, Superintendent of the West Haven, Conn., Sewage Treatment Plant.

"Preliminary Greenhouse Studies of Digested Sludge as a Fertilizer," by Dr. Herbert A. Lunt, Acting Head of the Department of Soils, Conn. Agricultural Experiment Station, New Haven, Conn. Following the presentation of this paper it was voted by the membership that the executive committee of the association should appoint a committee to work with Dr. Lunt on further experiments with sludge as fertilizer.

"Symposium on Emptying and Repair of Separate Sludge Digestion Tanks"—discussion opened by Henry W. Bauer, Superintendent of the Middletown, Conn., Sewage Treatment Plant, and Walter A. McMahon, Superintendent of the Torrington, Conn., Sewage Treatment Plant.

"A Demonstration on the Use of Safety Equipment in the Operation of Sewage Works," by Merrill L. Ingraham, Safety Instructor, U. S. Department of the Interior, U. S. Bureau of Mines, Washington, D. C.

Following a luncheon in the Embassy Room of the Hotel Kimball, a safety demonstration was presented.

Officers elected for 1946 were:

President: George H. Craemer, Hartford Conn.
First Vice-President: Thomas R. Camp, Boston, Mass.
Second Vice-President: LeRoy W. Van Kleeck, Hartford, Conn.

Directors: Howard F. Carpenter, Providence, R. I.
Ralph W. Horne, Boston, Mass.
R. S. Burr, Waterbury, Conn.
Secretary-Treasurer: Walter E. Merrill, Boston, Mass.

LeRoy W. Van Kleeck, *Secretary-Treasurer*

ROCKY MOUNTAIN SEWAGE WORKS ASSOCIATION

Ninth Annual Meeting

Denver, Colorado, September 20, 1945

The Ninth Annual Meeting of the Rocky Mountain Sewage Works Association was held at the Shirley Savoy Hotel in Denver, Colo., on September 20, 1945. A total of 90 members and guests was registered.

The meeting was called to order by President Dana E. Kepner at 10:00 A.M. for the first program contribution, which was a discussion by Chief Engineer B. V. Howe of the Colorado State Department of Health on the policies of that agency in regard to stream pollution control. Mr. Howe advised that 65 Colorado municipalities have been requested to provide adequate sewage treatment facilities in compliance with state laws and discussed the criteria by which the required degree of treatment has been determined in each case. A profitable general discussion followed.

W. V. Leonard, Chief Engineer of the Wyoming State Department of Health, in his address entitled "New Ideas Born of Wartime Necessity," reviewed his observations of design and operation practices in sewage treatment plants and cited instances in which emergency solutions of problems have resulted in new developments. He made particular reference to the advantages of stage treatment and of certain unusual combinations of treatment processes, based on the operation of plants which had been rebuilt to handle overloads.

At the Business Luncheon, a brief talk was given by W. H. Wisely, Executive Secretary of the Federation of Sewage Works Associations, on "The Aims and Accomplishments of the Federation." A paper presented by N. J. Castellan of the War Production Board revealed that it has been possible for many construction materials to be released for use but that certain items such as lumber and electric motors were still "tight." It was apparent from these remarks that sewage works construction will be hampered considerably for the next few months by the shortage of some types of materials and equipment.

The afternoon technical program opened with a paper by F. M. Veatch, of Black and Veatch, Kansas City, Mo., entitled "The Postwar

Outlook." Mr. Veatch outlined the uncertainties of the present in regard to construction and estimated that it may take as long as two years for conditions to stabilize. This paper served well to introduce the open discussion which concluded the meeting.

At the business meeting, a resolution inviting the Federation to hold a future annual meeting and convention at Denver was adopted unanimously. The following officers were elected to serve during the year 1945–1946:

President: John T. Franks, Omaha, Neb.
Vice-President: N. P. Nielsen, Pueblo, Colo.
Secretary-Treasurer: Carroll H. Coberly, Denver, Colo.
Federation Director: W. V. Leonard, Cheyenne, Wyo.

CARROLL H. COBERLY, *Secretary-Treasurer*

MEMBER ASSOCIATION MEETINGS

Association	*Place*	*Date*
New Jersey Sewage Works Association	Stacy-Trent Hotel, Trenton, N. J.	Mar. 20–22
New York State Sewage Works Association	Hotel Pennsylvania, New York City	Jan. 18
South Dakota Water and Sewage Works Conference	Lawler Hotel, Mitchell, S. D.	Dec. 6–7
Texas Sewage Section	————	Feb. 11–13

Federation Affairs

EIGHTEENTH ANNUAL MEETING OF BOARD OF CONTROL

The Eighteenth Annual Meeting of the Board of Control of the Federation was held in three sessions at the Hotel Stevens in Chicago on October 17–18, 1945. The sessions included the final meeting of the 1945 Board, the regular meeting of the Election Committee and the organization meeting of the 1946 Board. A total of thirty-seven officers, directors and committee chairmen were in attendance—an unusually favorable figure considering that the meeting was not held in conjunction with a convention of the membership-at-large.

This brief summary will present some of the major items given attention by the Board; detailed minutes of the meeting will be published in the January, 1946, issue of *This Journal*.

Designation of Annual Meeting

The minutes of the 1944 meetings of the Board were corrected in that the 1944 sessions at Pittsburgh had been incorrectly designated as the Sixteenth Annual Meeting, whereas it was actually the seventeenth time the Board of Control had met for the conduct of regular business. Future meetings of the Federation will be numbered accordingly, regardless of the succession of conventions.

New Officers

Officers elected for the year 1945–46 were: President—J. K. Hoskins, Assistant Surgeon General, U. S. P. H. S., Washington, D. C.; Vice President—Francis S. Friel, Consulting Engineer, Pittsburgh, Pa.; Treasurer—W. W. DeBerard, City Engineer of Chicago, Ill. (re-elected); Executive Secretary—Editor—W. H. Wisely, Champaign, Ill. (re-appointed); Advisory Editor—F. W. Mohlman, Director of Laboratories, The Sanitary District of Chicago (re-appointed). Harold Farnsworth Gray of Berkeley, Calif., was elected to the office of Director-at-Large for a three-year term ending in October, 1948.

Awards

Upon recommendation by the Committee on Honorary Membership, Dr. Willem Rudolfs, staunch supporter of the Federation since the time of its organization, was elected to the grade of Honorary Member. Dr. Rudolfs becomes the eighth Honorary Member of the Federation, this grade being limited to a maximum of ten living members.

The *Harrison Prescott Eddy Award*, for "outstanding research contributing in important degree to the existing knowledge of the fundamental principles or processes of sewage treatment," was granted to Lloyd R. Setter of New York City, in recognition of his contribution to Sewage Works Journal entitled "Modified Sewage Aeration."

The *George Bradley Gascoigne Award* was granted to John D. McDonald, formerly of Springfield, Mass., and now in military service, for his contribution to Sewage Works Journal entitled "Sludge Disposal Experiences at Springfield, Mass." This award recognized an "outstanding contribution to the art of sewage treatment works operation through the successful solution of important and complicated operational problems."

Presentation was authorized of the *Charles Alvin Emerson Award*, for "outstanding service in the sewerage and sewage treatment works field, as related particularly to the problems and activities of this Federation," to Harold Warner Streeter of Cincinnati, Ohio. The accompanying citation states that Mr. Streeter is so honored "in recognition of his valuable researches in the fundamental principles of the natural purification of polluted streams; of his service to the Federation during its organization and formative period and of his continuing loyalty to the well being of the Federation."

The *Kenneth Allen Awards*, for "outstanding service in the sewerage and sewage treatment works field as related particularly to the activity of Member Associations," were granted to the following: Joe Williamson, Jr. (Florida Sewage Works Association); Murray Alderson Wilson (Kansas Water and Sewage Works Association); George S. Russell (Missouri Water and Sewerage Conference); Frederick Holman Waring (Ohio Sewage Works Conference); Howard Eugene Moses (Pennsylvania Sewage Works Association); Dario Travaini (Arizona Sewage and Water Works Association).

Several years of study and effort by the Committee on Operation Reports culminated at this meeting in the authorization of a new award, to be known as the *William D. Hatfield Award*. This prize will be conferred upon the author of the most outstanding annual sewage works operation report, as judged by authorized clearing committees in each Member Association and finally by the Committee on Operation Reports of the Federation. The Executive Secretary was instructed to initiate this activity immediately in the hope that the first award might be made in 1946.

Committee Reports

The Committee reports presented to the Board at this meeting were notable for the interest and effort represented on the part of all committee personnel. Many of the reports cited the excellent progress which is being made in the performance of committee functions.

The report made by Chairman Cohn of the Sewage Works Practice Committee was particularly significant. Mr. Cohn discussed the success of the first manual of practice entitled "Occupational Hazards in the Operation of Sewage Works" and reported that the manual to be entitled "Utilization of Sewage Sludge as Fertilizer" is expected to issue early in 1946. He continued with a timetable on other manuals, stating that those on sewage chlori-

nation, trickling filters, and sewer ordinances were expected to be developed in 1946 while the manuals on plant operation reporting units, sewage aeration and on sewer maintenance would probably reach the production stage in 1947.

The Committee on Sewage Works Nomenclature reported that the glossary of Water and Sewage Control Engineering has cleared through the hands of Editor C. L. Bogert early in October and would be submitted to the printer at an early date. The glossary is a joint project of the Federation with A.S.C.E., A.P.H.A. and A.W.W.A.; it will be furnished to members of the Federation as a special manual of practice.

The Committee on Qualifications of Sewage Works Operators presented a final report which was accepted by the Board of Control. The report sets forth current practices in registration and certification of sewage works personnel and offers recommendations for the guidance of agencies interested in the establishment of such programs. The committee has been retained in service for the purpose of activating its requirements.

A new committee, to be known as the Legislative Analyses Committee, was created by the Board and personnel are to be named later by President Hoskins. This committee will study state and national legislation pertinent to the interests and objectives of the Federation and will advise the Board of Control in such legislative matters.

Journal Improvements

Upon the recommendation of the Publications Committee, the Board authorized the Editor to adopt a two-column page to replace the full measure format now used in Sewage Works Journal. The new two-column page has been presented experimentally in the Sewage Works Equipment and Supplies Section of the September *Convention Number* for the past several years and incorporates several advantages from the standpoints of the reader and of mechanical production. The new format will be introduced with the January, 1946, issue.

With a view toward better service to the users of the *Journal*, the Board instructed the Publications Committee to undertake a detailed study of the possibility of producing the *Journal* on a monthly instead of a bimonthly schedule. The study and reports is to be processed through the Executive Committee for presentation to the Board at the next annual meeting.

Membership Activities

The Executive Secretary reported that the combined Active and Corporate membership of the Member Associations of the Federation totaled 3,216 on September 30, 1945, representing a gain of 228 members or 7.6 per cent during the year ended on that date. Under the rules of the 1945 membership contest, the Canadian Institute on Sewage and Sanitation—with a gain of 72 members during the contest—earned the right to assign the numerical increase prize and the Arizona Sewage and Water Works Association won the privilege of assigning the percentage increase prize by virtue of its recorded gain of 140 per cent. The individual recipients of these prizes will be announced later.

The Board authorized continuation of the membership contest in 1946, providing for cash prizes of $100 each to be awarded directly to the Member Associations enrolling the greatest percentage and numerical increases in membership.

Nineteenth Annual Meeting

The Nineteenth Annual Meeting of the Federation, to be combined with a convention of the membership-at-large, will be held at Toronto, Ontario, Canada, with the Hotel Royal York as headquarters. Tentative dates for the meeting are October 7–9, 1946.

At this meeting, a new type of entertainment will be initiated with a view toward the elimination of conflicting entertainment in private rooms. The so-called "Club Room" entertainment has been found to be highly successful as conducted at several meetings recently and came to the Board as a recommendation of the W. & S.W.M.A. The Board also acted to endorse this type of entertainment for adoption at Member Association meetings.

Action on Legislation

A recently amended draft of the Spence Bill (H.R. 4070) was considered by the Board and action was taken to reaffirm the resolution which was adopted on this bill as presented in the 78th Congress (see *This Journal*, **17**, 2, 392—March, 1945).

Because of its potential beneficial effect in the elimination of industrial stream pollution, the Board acted to endorse in principle the Bailey Bill (H.R. 3972), which would allow an industry to deduct the cost of waste treatment works in the computation of net income for tax purposes.

The Executive Secretary was instructed to transmit the views of the Board to each member of the congressional committees in which the above bills are under consideration.

Joint Luncheon with C.S.S.W.A.

At the conclusion of the business meetings, officers and members of the Federation Board of Control were guests at a luncheon sponsored by the Central States Sewage Works Association on October 18. A total of 135 persons were in attendance.

Dr. A. E. Berry, retiring President of the Federation, presented the principal address at the luncheon, his subject being "Responsibilities of the Sewage Works Field in Meeting its Greatest Challenge." Following the luncheon provisions were made to conduct those interested on tours of inspection of the Southwest Sewage Treatment Works of the Sanitary District of Chicago and through Chicago's new South District Water Filtration Plant.

W. H. W., *Executive Secretary*

Reviews and Abstracts*

Conducted by
GLADYS SWOPE
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NOTES ON THE DEVELOPMENT OF A SEWAGE PURIFICATION WORKS (CANTERBURY) †

BY N. P. BUTTERWORTH

The first step in sewage treatment made by the Canterbury Corporation was taken in 1868. At that time tanks and straining filters were provided. This system was a failure due to the large quantities of solids discharged to the river with the effluent. Land treatment was then adapted, using an area of twenty acres. The tank effluent was pumped at a steam pumping plant to a series of distributing manholes, and the land effluent was drained to the old effluent sewer. Later another fifty acres of land were added.

In 1905 new tanks were constructed to replace the old, and electrically driven pumps were provided in place of the steam plant. In 1914 six percolating filters were built to supplement the land filtration system. Additional filters, the last of which were built in 1928, ultimately displaced the land filtration areas.

Alterations having been made without regard to ultimate design, it is not surprising that the layout lacks compactness which is so desired in a modern plant. At this time it is necessary to survey the situation and decide what is needed to make the plant more flexible.

The following notes were prepared as a preliminary basis for discussion and only represent the views of the author. The population served is approximately 25,000. The sewage is medium and chiefly domestic with an oxygen absorbed in 4 hours of 132.8 p.p.m. The flow is about 1.2 m.g.d. (Imp.).

As the sewage enters the plant it is screened through 3-in. bar screens. These have proved quite satisfactory. Following the screens there are two grit chambers, constructed in 1928. They are 32 ft. by 12 ft., and as originally built had hopper bottoms. These hoppers were not satisfactory and were filled in to form flat bottom tanks with small pits at the centers for the power operated grit elevators. The tanks were still unsatisfactory as the velocity at normal flow was but 0.14 f.p.s. In 1932 two intermediate walls were built in each tank to form continuous channels. This change increased the velocity to 0.5 f.p.s.

The screens following the grit chambers are bar screens with ½-in. openings. They are mechanically raked, and as originally installed had two rakes on each machine. Improved operation has been realized by increasing the number of rakes to four with alternate teeth on each rake removed. It has been found advantageous to discharge the screenings back to the chamber during dry weather as the constant pulverising and washing materially reduces the quantity for ultimate disposal.

The sewage pumping plant consists of three 100,000-g.p.h. (Imp.) and one 200,000-g.p.h. centrifugal pumps driven by direct current motors of 20 and 37 h.p., respectively.

*** It will be appreciated if Miss Swope is furnished all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in THIS JOURNAL. Publications of public health departments, stream pollution control agencies, research organizations and educational institutions are particularly desired.**

† Presented at a Meeting of the Metropolitan and Southern Branch of the Institute of Sewage Purification (April, 1945).

Three storm water pumps are provided with capacities of 160,000, 250,000 and 375,000 g.p.h. Most of the plant has been in operation for 40 years.

The storm water pumps are in much better condition than the others and it is proposed that the sewage and storm water be pumped by these units as they have ample capacity and the cost of new sewage pumps would be avoided.

There are ten rectangular flat bottomed settling tanks, four of which are 24 ft. by 30 ft. by 8 ft. and six are 38 ft. by 50 ft. by 10 ft. It appears that originally there were four tanks, two detritus tanks about 61 ft. long and two for septic action about 120 ft. long. It seems that more was expected of the septic tanks as a report in 1908 voiced a complaint that they were not doing their work in spite of the fact they had not been cleaned in *2 1/2 years.* Later the tanks were subdivided to the present measurements. As now operated sludge is removed from the smaller tanks once a week and from the larger tanks about once every 2½ months.

About 1900 provision was made for treating storm water by the construction of a three acre straining filter of ballast and clinker. The filter was not entirely successful due to sealing with solid matter and later a settling tank was provided. In 1929 the layout was abandoned and three storm water tanks built. Each tank was 120 ft. by 36 ft. in plan with an average depth of 4 ft. 6 in.

It is now believed that the storm tanks could be utilized for sewage and storm water, thus eliminating the ten old settling tanks. They are well situated and could form the nucleus of primary settling and balancing tanks. As the primary tank effluent would contain settleable matter of a finer character it is proposed that secondary settling tanks to give a two-hour period be provided.

There are fifteen circular filters, six of which were built in 1914. The others were added at three different times. Thirteen units are 87 ft. in diameter and two are 80 ft. diameter. The combined volume is 16,200 cu. yd. The flow is not well balanced between the various units, and it is because of this that the proposal in connection with secondary settling tanks is made.

All filters were originally 80 ft.. diameter. Disintegration of the walls made new construction necessary and the opportunity was taken to increase the size to 87 feet. The rate of dosing is about 75 gal. per cu. yd., dry weather flow. This is rather high but effluents have been satisfactory.

Space is available for more filters and they can be constructed when required. The possibility of using alternate double filtration has been considered and the method can be adopted without changing the basic character of the scheme.

There are three humus tanks with a capacity of 264,000 gal. Two were built rather recently and are of the shallow rectangular type. The other tank was built in 1914 and is much deeper. It is proposed to reduce the depth of this tank and to provide two more tanks of similar design. The new scheme includes means for regulating the flow to the tanks.

The first attempt at sludge drying was made in 1905 when six sludge filter beds were constructed. They were each 30 ft. by 25 ft. and as an extra refinement Dutch barns were erected over them. In 1928 additional facilities were added when a shed 425 ft. long and 36 ft. wide was erected for drying sludge. The original beds were converted to dewatering beds and when the sludge reached a thick consistency it was scraped off and elevated into wagons which delivered it to the new beds. The floors of the new beds sloped one foot from front to back and were covered with ballast and ashes. Dried sludge was carted to a stone crusher where it was broken up and bagged. The scheme was not a solution to the sludge drying problem as there was not sufficient room available. In 1932 the shed was reconstructed to form eleven separate beds. Sludge is pumped to them, and the old covered beds have reverted to type.

T. L. HERRICK

SEWAGE TREATMENT PLANT, DALLAS, TEXAS

Second Annual Report

1944

By L. C. Billings

This comprehensive report is prefaced by a detailed history of sewage treatment in Dallas, prepared by Margaret M. Roddy, Junior Chemist. The history follows the development of sewage treatment from the first plant, consisting of 12 Imhoffs and one sludge drying bed, installed in 1917, to the present trickling filter plant which was placed in operation in 1940. An inventory of equipment, with sizes and capacities, is included. It is planned to keep the history current by adding supplements in future reports.

The present plant, designed to serve a population equivalent of 500,000, consists of two sewage pumping stations, bar screens, grinder, grit channels, grease removal and odor control, 2 primary settling tanks, 24 Imhoffs, 4 batteries of 4 circular rock filters each, 3 final settling tanks, and 2 sludge digesters. The final sludge is discharged to two lagoons. Provision has been made for future expansion.

The plant was operated without incident during 1944. It was shut down for 70.6 days, 11 because of high water and 59.6 due to the inadequacy of one pump station. Plant effluent was recirculated to the filters to keep the stones moist while the plant was being by-passed. Seventy per cent of the primary sludge was run to the digesters, the remainder to the lagoons. A heavy load of industrial wastes, comprising packing-house, cottonseed oil, soap manufacturing, dairy, and garage wastes, is handled. A flock of sheep was kept on the grounds to keep weed growth down but after several years experience it appears that the care of the sheep and the damage to shrubs and plants more than offsets the value of the weed eradication.

Operating results are presented in 13 tables and three charts. The results are abstracted in the following compilation.

	1944	1943
Cost of operation/m.g.	$5.22	$5.51
Monthly average of sewage pumped at plant, m.g.	627.7	607.9
Monthly average, power consumption at plant, kwh.	30,466	26,250
Monthly average, grit, cu. ft.	4,040	4,568
Settleable solids, raw sewage, p.p.m.		
Average	10.5	11.1
Maximum	18.0	17.0
Minimum	6.0	3.0
Settleable solids, final effluent, p.p.m.		
Average	0.2	0.2
Maximum	3.5	2.5
Minimum	tr	tr
Ammonia nitrogen, raw sewage, p.p.m.		
Average	26.9	27.6
Maximum	36.8	35.0
Minimum	18.6	16.8
Ammonia nitrogen, final effluent, p.p.m.		
Average	20.4	18.9
Maximum	34.0	36.8
Minimum	12.3	9.8
Organic nitrogen, raw sewage, p.p.m.		
Average	23.1	19.1
Maximum	40.6	32.9
Minimum	12.6	9.8

	1944	1943
Organic nitrogen, final effluent, p.p.m.		
Average	7.8	5.4
Maximum	14.0	19.6
Minimum	4.2	2.1
Oxygen consumed, raw sewage, p.p.m.		
Average	119	110
Maximum	166	170
Minimum	62	68
Oxygen consumed, final effluent, p.p.m.		
Average	34.6	30.0
Maximum	46.5	39.5
Minimum	21.5	16.8
B.O.D., raw sewage, p.p.m.		
Average	377	349
Maximum	570	607
Minimum	188	120
B.O.D., final effluent, p.p.m.		
Average	40	39
Maximum	111	74
Minimum	10	11
D.O.,* final effluent, p.p.m.		
Average	3.7	5.8
Maximum	7.2	8.0
Minimum	0.0	2.4
Filter loading, Lb. B.O.D./acre ft.		
Average	1,409	963
Maximum	1,593	1,197
Minimum	1,082	690

* Under normal conditions the raw sewage, the primary, and the Imhoff effluents contain no dissolved oxygen.

Three charts show graphically by months the river stage and rainfall, B.O.D. removal, and suspended solids reduction at the various stages in the treatment process.

Supplement No. 1

PRELIMINARY STUDY ON SLUDGE FERTILIZER VALUE

An investigation was conducted to determine the fertilizer value of Dallas sewage sludge, to compare it with that of other cities which utilize sludge commercially, and to provide data for the possible installation of sludge drying equipment.

Samples of sludge were analyzed over a period of five months with the following results:

	Per Cent			
	Humus	Total N	P_2O_5	K_2O
Secondary tank sludge, Ave.	72.3	4.60	4.41	
Max.	79.0	5.51	5.25	
Min.	62.0	3.76	3.90	
Primary digested sludge, Ave.	52.1	2.34	3.05	0.096
Max.	58.1	3.92	4.37	0.097
Min.	47.3	1.90	2.28	0.095

These values were comparable with those obtained on digested sludge produced by other cities.

The value of the sludge was tested by studying its effect on two comparable potted plants, one of which was supplied with 50 grams of dried, digested sludge. This test showed that the sludge promotes vigorous growth and increases the moisture holding content of the soil.

It was decided that while the results were not conclusive, they were sufficiently interesting to warrant carrying on the study for another year.

SUPPLEMENT NO. 2

POLLUTION OF TRINITY RIVER THROUGH DALLAS COUNTY

This report was prepared through cooperation between the City of Dallas, the Dallas County Health Unit, and the Texas Department of Health.

The object of the report was to study the cumulative effect of pollution on the river in its passage through Dallas County. A comprehensive sampling program was outlined which had to be curtailed somewhat because of limited personnel and a desire to complete the work without interference from flood waters.

The results are presented in a series of tables and charts. The study was general in nature and the data collected were inadequate and of insufficient accuracy to provide completely dependable results. It was shown, however, that Trinity River is highly polluted as it enters Dallas County and that it receives no significant quantity of pollutional waters as it passes through the county. It was recommended that D.O., B.O.D., and M.P.N. be determined daily at a series of sampling points during all periods of low runoff and that limits of pollution be thereby established as a protection to the public.

RICHARD D. HOAK

THE POTOMAC RIVER BASIN—AN INTRODUCTORY REPORT

Published by the Interstate Commission on the Potomac River Basin
Washington 6, D. C. (1945)

This report is the first to be printed by the Interstate Commission on the Potomac River Basin which developed from the Potomac River Conservancy District recommended to the National Resources Committee in July, 1935. The Interstate Commission was authorized by Act of Congress July 11, 1940, and in turn the states comprising the Basin —Virginia, Maryland, West Virginia, Pennsylvania, and the District of Columbia—signed the compact.

The purposes of the Commission are:

"1. To coordinate, tabulate, and summarize existing data on the pollution, character, and condition of the streams of the Conservancy District.
2. To supplement existing data, if necessary, by conducting investigations.
3. To promote adoption by the signatory bodies of uniform legislation for the control of stream pollution.
4. To disseminate information to the public on the effects of stream pollution and the objectives of the Commission.
5. To cooperate with other organizations in, and conduct, if advisable, studies of treatment methods for sewage and industrial wastes.
6. To recommend to the signatory bodies standards for cleanliness of streams.

"The parties signatory to the compact mutually agree to:

1. Faithful cooperation in the abatement and control of pollution in the streams of the Conservancy District.
2. The enactment of adequate and, in so far as practical, uniform legislation for the abatement and control of such pollution.
3. The appropriation of funds to finance the operations of a coordinating agency."

The early history of the Potomac River is given with some detail. The growth and development of the area is marked by the discovery of coal in 1804, which brought need for freight transportation. This need was answered at the time by the Chesapeake & Ohio Canal constructed from Cumberland, Maryland, to Washington, D. C. It was used for navigation from 1831 until 1924 to carry flour, grain, lumber, building stone and other commodities.

With the establishment of the seat of the Federal Government in 1791 further important service of the river was required. The establishment of the District of Columbia has naturally exerted a strong influence in the development of the Basin. The Basin is divided by nature into two distinct portions, the upper region, generally that above Washington, D. C., is characterized by geologically young streams, and below Washington, the river is tidal and is, therefore, broad and sluggish in nature. One of the scenic spots of the East is that of the Great Falls of the Potomac, fifteen miles above Washington. This is one of the transition points between the two portions of the Basin.

Of the fifteen major cities in the Basin Washington, D. C., is the largest with the metropolitan area population well over a million. The entire watershed had an estimated population of 1,986,000 in 1943, with about one-third of this population rural.

Natural resources of the Basin are extensive and diversified. They include forest lands, which shelter much wild life. Fish life abounds in the streams of the Basin, varying from game fish from the upper Potomac and its tributaries to commercial fishing on the lower Potomac. The yields of the lower Potomac include oysters and crabs.

The Basin has many attractions for recreation because of its location near many urban centers. In addition to those of fishing and other water uses in the upper Potomac, large areas for yachting, canoeing and sailing are to be found in and below Washington. The Basin contains large areas of federal and state owned areas which are used for national parks, monuments and scenic drives.

Mineral resources of the area include, in addition to coal, low grade iron ore, ocher, sand stone, quartzite, gypsum, gold, copper and molding sand. Also the Basin produces fire clays, common clays, limestone, cement and other road materials, volcanic rock, ganister, glass sand, manganese ore, gravel and sand.

The development of water power is possible because of the many dam and reservoir sights offered in the Basin. At the present time there are no hydroelectric plants of any size.

Within the Basin there are many domestic and industrial water supplies, both surface and ground water. On a population basis the Potomac River is the principal supplier of water because of this service to Washington, D. C. Of the 184 water supplies in the Basin 131 are public supplies with the remainder for industrial use. The pollution problem within the Basin is concerned with both sanitary sewage, industrial waste and acid mine drainage. The washing of silt from the area of the Basin for final deposition in the lower river is also a problem increasing in magnitude.

The watershed has 154 communities with a population over 500. Of the 190 million gallons of sewage discharged daily by the urban area 20 million gallons receive no treatment, 153 million gallons daily receive primary treatment and 17 million gallons daily complete treatment. With a contributing population of 1,520,000, treatment reduces this in effect to a population loading of approximately 1,000,000 persons. The Basin has about 50 communities over 500 population which do not have public sewers.

While the Basin is not heavily industralized, there are some areas which give serious industrial waste treatment problems. Of the 98 industries recorded as discharging their wastes to streams directly rather than through a municipal sewer system, 48 treat their wastes to reduce the pollutional load on the receiving stream. The estimated flow through these treatment works is 32 million gallons daily. The 50 plants which do not treat their waste have a combined discharge of about 21 million gallons daily. The report gives in tabular form the locations and population equivalents of these sources of pollution. The total industrial waste loading allowing for treatment amounts to approximately an equivalent population of 495,000.

Acid mine drainage has been reduced to a degree by sealing of abandoned mines. The effect of this drainage is serious enough to interfere with fish and plant life at

numerous points in the watershed. It is estimated at the present time that 172,800 pounds of acid per day are discharged into the streams of the area and after all economic sealing has been done, the discharge will still be 110,000 pounds per day. The effects of pollution vary within the Basin according to the conditions at that point. Some places exhibit the effect of a single pollutant, while others show combined effects of pollutional materials. Areas pointed out as problem areas are Luke-Cumberland and the Washington, D. C., area.

Other problems of the Basin referred to in the report include flood protection, erosion, mosquito control and the water chestnut. In conclusion the report states that the Potomac River Basin, because of its natural situation, offers excellent opportunities for expansion to the industrialist, farmer and recreation seeker. The river like many others in the United States must assimilate the wastes of cities and industries and at the same time be kept in a condition suitable for other river uses. The Commission intends to plan and promote through established state agencies a program for pollution control which will be an asset to the entire Potomac River Basin.

As an appendix the Public Resolution No. 93, 76th Congress, is given as passed by the Senate and House of Representatives of the United States. The report also gives the list of its officers and representatives from the District of Columbia and four states which are the signatory bodies. Also included is a list of committee personnel of the Commission.

The 61-page report includes two tables and 19 figures consisting of photographic views in the Basin and graphic representation of the available data. These illustrations compliment the text so that the entire report is complete and highly informative.

RALPH E. FUHRMAN

PROCEEDINGS OF THE TWENTY-SIXTH TEXAS WATER WORKS AND SEWERAGE SHORT SCHOOL, 1944

Fitting a Sewage Plant Effluent to the Stream That Is to Receive It. By E. J. M. Berg, pp. 111–114. See *This Journal,* **16,** 835 (July, 1944).

A Unique Method of Gas Collection and Utilization at Sewage Plants. By J. P. Burden, pp. 115–117. See *This Journal,* **16,** 801 (July, 1944).

High Rate Biological Filters. By Captain R. M. Dixon, pp. 117–119. Some of the changes effected in the development of the high rate filter were: (a) improvements of distributor construction and operation so that the influent is more evenly distributed over the entire surface of the filter, (b) recirculation in order to dilute the filter influent, (c) recirculation in order to smooth out periods of low flow and otherwise maintain an even rate of application throughout the day.

Biological beds operating under high B.O.D. loads must depend upon dispersed small organisms that can operate under low oxygen tension. Filters operating under these conditions are capable of appreciable reduction of the carbon cycle but the longer, later nitrogen cycle is seldom affected. Nitrification does not readily occur and methylene blue relative stabilities on unchlorinated effluents are very low. Secondary sludge fed to the filter influent improved one plant's efficiency and eliminated fly and odor nuisances.

The only construction economy effected by the high-rate filter process is in the cost of the filter unit. Offsetting this saving is the cost of recirculating pumping equipment and housing and increased settling and sludge digestion capacity. Operating costs are higher in the case of the high-rate filter.

Auxiliary Methods of Removing Grease from Army Sewage. By Rolf Eliassen and H. B. Schulhoff, pp. 119–131. Analyses of Army sewage for grease content have indicated daily averages of from 25 to 250 p.p.m. of petroleum ether soluble matter, with peak values running up to 1,000 p.p.m. over short periods of time. These values are far above those of ordinary domestic sewage.

Experience has indicated that grease containing substances will digest giving a high yield of gas and if the grease is well interspersed among the other solids, no difficulty

need be experienced in the digesters. However, in many instances the grease will separate from the other sludge particles and form a hard mat many feet thick. Most satisfactory results on the digestion of grease without difficulties have been obtained at those plants in which the primary digesters were provided either with high speed mechanical stirring devices or sludge recirculation into the scum zone at the point of entrance of raw sludge into the digester.

Grease removal methods have included the following: plain skimming tanks, chemical precipitation, diffused air aeration, mechanical aeration, aero-chlorination, vacuum flotation.

A study was made of the various methods and the results are presented in tabular and graphical form. The conclusions drawn from these studies are as follows:

(1) Diffused air aeration had no appreciable effect on increasing grease removal over the removal accomplished by plain settling.
(2) Aero-chlorination with 5 or 10 p.p.m. of chlorine gas added to the air being diffused into the sewage had no effect on increasing grease removal.
(3) Mechanical aeration increased the removal of grease a few per cent when grease was present in the raw sewage in concentrations over 100 p.p.m. Approximately 50 per cent of the grease was removed in the aeration unit.
(4) Aero-chlorination with 5 p.p.m. of chlorine gas showed no further increase in grease removal over that obtained by mechanical aeration.
(5) Vacuum flotation increased the removal of grease a few per cent when the grease in the raw sewage was over 150 p.p.m. Over 75 per cent of the grease was removed in the flotation unit.
(6) Aero-chlorination with chlorine up to 25 p.p.m. added in the aeration stage preceding flotation showed no effect on increasing the removal of grease.
(7) Plain settling is one of the most effective means of removing grease from raw sewage.

In discussing this paper W. S. Mahlie points out that the grease received at the ordinary sewage treatment plant is not nearly as pure as that recovered from kitchens. It contains large quantities of mineral oils. True fats consist of a glycerine base united to a fatty acid constituent. Fats are being saved not for the fatty acids but for the glycerine which can be converted into explosives.

Regional Planning of Sewage for Housing Subdivisions. By Joe B. Winston, pp. 131–134. Individual septic tanks for large housing projects failed for many reasons. The main reasons were poor soil conditions, bad climatic conditions, improper design, poor construction, and the fact that septic tanks do not work in groups or large numbers side by side. First attempts at a solution were to improve the specifications of the septic tank and strengthen the inspection and approval system. The individual septic tank system still proved to be a failure in group housing. The next step was to establish the rule that no subdivision would have government assistance or approval without provisions for safe, adequate drinking water and a complete sewage disposal system. However, with rapid housing development this procedure also proved unsatisfactory. For example it would have meant 9 complete sewage treatment plants in an area of six square miles. The idea of regional planning or simple consolidation was brought out at this point and the problem began to show signs of a solution. Water supply and sewerage are both being handled on a district basis rather than on the basis of individual houses or small subdivisions.

Some Suggestions for a Small Town Sewage Plant. By S. L. Allison, pp. 134–136. A brief commentary on the need for sewage treatment, financing problems, odor problems, chemical treatment, sludge and screenings disposal.

The Small Town Sewage Treatment Plant—the Operator's Viewpoint. By H. D. McAfee, pp. 136–138. A discussion of ways and means for improving plant operation and maintenance. The importance of daily records on plant operation is stressed.

The Consulting Engineer's Viewpoint of the Small Town Sewage Treatment Plant. By Julian Montgomery, pp. 138–141. The consulting engineer's viewpoint must embrace the following:

(1) The selection of the proper type of plant for the particular town.
(2) The adequate and correct design of the type of plant selected.
(3) The proper operation of the completed plant.

The type of plant to be selected for the small town must meet the following requirements:

(1) Ordinary, inexpensive operation of the plant must produce an effluent of a quality sufficient to meet the requirements of the environment.
(2) Odor control must meet the requirements of the location of the plant site.
(3) The capital cost of the plant must be within the financial ability of the town.

The consulting engineer should provide for convenience and safety in plant operation. The degree of treatment to be provided will depend on the character of the body of water receiving the plant effluent. Where pumping is required two pumps should be provided and the wet well should be designed so that there will not be long intervals between the operation of a pump during minimum flow. In all cases where the raw sewage is pumped, the pump flows must be considered in the design for every unit of the plant.

Centrifuging Sewage. By Paul J. Gresham, pp. 141–144. A centrifuge multiplies the force of gravity and hence accelerates the normal process of sedimentation. To centrifuge sewage successfully on a large scale a means of continuous sludge removal from the centrifuge must be provided. The power requirements must be low enough so that when efficiency of solids removal is considered the method of centrifuging can compete with conventional sedimentation equipment. Studies have been made on an experimental centrifuge unit and the following operating results are given:

Sample No.	B.O.D., p.p.m.		% Removal	Susp. Solids, p.p.m.		% Removal
	Raw	Effluent		Raw	Effluent	
1	307	121	60	228	22	91
2	330	159	52	266	12	95

The centrifuge was so designed that the effluent is oxygen saturated. Sludge from the centrifuge is so concentrated that in some cases water must be added to secure flow in pipes.

Centrifuging has no effect on dissolved solids and by itself does not provide complete treatment. Conventional secondary treatment units should follow centrifuging if complete treatment is necessary.

A Field Determination for Dissolved Oxygen. By W. P. Walker, Jr., pp. 144–145. A description of the Winkler and modified Winkler methods for dissolved oxygen determinations is given. Field experience has indicated that moderately accurate results may be obtained by simply immersing sample bottles in the water to be tested until the bottle is filled and then stoppering tightly until the analysis is begun.

PANEL DISCUSSION: THE HAYS PROCESS OF SEWAGE TREATMENT, pp. 145–157.

The Designer's Angle. By S. C. Cooper, pp. 145–148. In the past the engineer who has been called upon to design a Hays process sewage treatment plant has often been given conflicting design criteria.

Design criteria used for a recently designed municipal plant are as follows: Air requirements: 0.9 cubic feet per gallon; contact media: 123 square feet per pound of applied B.O.D.; primary tank detention time: 2 hours; intermediate tank detention time: 1.25 hours; final tank detention time: 1.75 hours; sludge digestion: 3.5 cubic feet per capita; sludge beds: 0.8 square feet per capita. Air diffuser tubes were used rather than pipe grids for supplying air to the contact media.

The biggest problem with the Hays process or for any type of sewage treatment has been the upsetting of the bacteriological action by shock loads. These are frequently caused by the direct return of the sludge supernatant to the plant flow. The supernatant can be treated by providing a small aerator and sedimentation tank.

The structural design of a Hays process plant is fairly simple.

A plant designed for the City of Big Spring (design population 20,000) will cost $6.37 per capita to build and $0.65 per capita per year for operation. The operating cost includes a reserve fund sufficient to provide for the replacement of all mechanical equipment each ten years. This does not take into account the revenue from the sale of the effluent which will be used for industrial purposes at a refinery.

Many of the problems at Hays plants have been associated with faulty operation rather than poor design.

The Hays Process—New Developments. By Quintin B. Graves and Luis Pachon Rojas, pp. 148–151. Air distribution may be improved by staggering the orifices in the air grids so that there will be no dead spaces between any of the plates or by decreasing the size and spacing of the orifices to obtain the same result. No clogging of orifices in plastic tubes has been reported, but some of the plastics become brittle and break while in use. The best solution for air distribution may prove to be porous diffuser air grids. This produces a circular type of circulation similar to that found in activated sludge plants. There is no spiral flow however because of the contact plates. Another method of air application which is being tested is to merely run a number of pipes vertically downward into the sewage below the contact media with the open end pointing downward. A variation has been to attach a fish-tail discharge piece to the open end of the pipe, similar to the fish-tail piece used on a Bunsen burner.

Digester supernatant has a deleterious effect on plant operation. At one plant a conditioner has been provided. This consists of an aeration tank in which a mixture of supernatant and sludge from all tanks is aerated for about 15 hours and then allowed to settle. After settling the liquid was added to the influent and the solids were added to the digester. This was only moderately successful in preventing plant upsets, however. A better procedure was to mix equal portions of aerator sludge and supernatant and then aerate the mixture for 15 hours. Very few anaerobes were present in the resulting supernatant.

It has proven profitable to provide removable grids. Drains for orifice type grids may prove of value.

Army Experiences with Hays Process Sewage Treatment. By Capt. Ben. L. Grimes, pp. 151–153. For a period of time following the original installations, the performance of the Hays plants at Army posts was complicated by design errors, inexperienced operators, conflicting operating instructions, and various experiments. In addition designers in many instances were not furnished with definite information as to the plant loading.

One of the most frequent sources of difficulty has been the submerged wrought iron or steel pipe grid systems which are subject to corrosion and clogging. In many plants the effect of orifice clogging has been reduced by the installation of an overhead air supply system and removable grids which can be serviced without taking the aerators out of service.

In a few plants grids of asphaltic fibre conduit material were installed but were not successful.

The majority of plants have been equipped with three positive displacement blowers. One was to act as a standby unit. Use of all three blowers was necessary in most instances.

Lagooning of the supernatant before returning it to the plant seems to be the most successful means of handling supernatant.

At present very few of the Hays process plants in the Eighth Service Command are giving trouble.

Hays Sewage Treatment Process from the Operator's Viewpoint. By Lt. J. A. Drake, pp. 153–156. Primary clarifier detention times should be carefully checked. Detention times of beyond 2 hours are of doubtful value in per cent removals and may be very deleterious because of the increased septicity of the sewage causing a serious lag in the first stage aerator.

Digester supernatant is invariably a problem. Lagooning and lime treatment of the supernatant have been used. Care must be exercised in the use of lime since too much will drug the biological activity of the digesters.

Many difficulties have been encountered with air distribution. Various plans including the use of diffuser tubes have been tried. The latter have increased plant efficiency. In one plant where diffusers were used, the hoppers in the bottom of the aeration tanks were eliminated. This had no apparent ill effects.

The aeration should be tapered so that the first tank gets the most air and each succeeding tank somewhat less.

Sludge hoppers in the various aeration and settling tanks should be drained regularly to prevent gas lifting of the solids.

Odors originate mainly in the first stage aerator. Characteristic of the Hays process is the abundance of sulfur-loving micro-organisms in first-stage aerator. Establishing an oxygen residual in the first-stage aerator by increasing the air or by recirculating effluent from the final aerator helps materially in reducing odors.

The Need for Sanitary Research. By B. F. Williams, pp. 157–158. Future industrial development in Texas will be limited by the water supply available. At present approximately 80 per cent of the water consumed in the State is secured from ground sources. However, much ground water is unsuitable for some industrial processes without treatment. The total flow of all Texas streams, if properly controlled, would be adequate for water supplies and waste disposal with proper waste treatment. The disposal of raw industrial waste into surface streams is a threat to the State's water resources and the pollution problem will greatly increase as the State becomes industrialized.

If and when the State becomes industrialized a great deal of investigation and research must be devoted to proper treatment of sewage and industrial wastes.

Operation of the Salt Water Control Plan in the East Texas Oil Field. By M. F. Granville, pp. 158–159. One third of the East Texas oil field, covering the greater part of five counties, is situated on the Neches River watershed and is drained by various tributaries into the Neches River. Water from the River is used for domestic and industrial purposes. This water, besides meeting other standards of chemical purity, must not contain more than 17 gr. per gal. of sodium chloride. In 1940 when the East Texas field began production of salt water in quantities and without facilities for handling it, the quality of the water in the Neches River was menaced. The Attorney General brought suit against 155 East Texas oil field operators, charging them with pollution of the waters of the Neches River above statutory limits. On the request of the oil operators, the trial was postponed temporarily to allow the operators to develop a plan which, if successful, would prevent further pollution of the Neches River.

A governing committee on salt water control for the East Texas oil field was formed. This committee consists of the heads of four state departments; namely, the health department, attorney general, board of water engineers, and the fish and game commission. Funds for administration are derived from a $1.50 oil well fee on all wells producing more than 5 per cent salt water.

At present there are 25,000 wells in the East Texas field and some 5,000 are located on the Neches River watershed. Of the latter approximately 700 are producing water in quantities ranging from a few barrels to 700 barrels of salt water per day. The chloride content of the salt water approximates 40,000 p.p.m. Some 133,000 barrels of brine are produced daily on the Neches River watershed, of which some 107,900 barrels are injected into brine disposal wells and the balance goes into surface pits and is disposed of by controlled dilution.

Since October 1942, about 50 per cent of the water produced has been disposed of by injection wells. When these injection systems take the entire daily production the quality of the river water will be adequately protected. However, it will be necessary to entirely empty the present earthen pits which are subject to seepage and it will probably take 10 or 15 years for sub-surface waters to drain out the salt accumulations from this field.

PAUL D. HANEY

SEWAGE DISPOSAL—A COUNTY-WIDE PROBLEM

By E. A. Holbrook

Greater Pittsburgh, 26, 16–17, No. 7 (July–August, 1945)

Since 1923, the protection of the purity of water within the Commonwealth has been the duty of the State Sanitary Water Board. The acts of 1905 and 1923 defined stream pollution as the discharge of sewage injurious to public health. This limited the powers of the Board because an actual health menace had to be shown before an abatement order could be issued, and, as a result, stream purification was scattered and local.

In 1937 an act was passed which greatly increased the scope and powers of the Board by forbidding the discharge of polluting industrial wastes and sewage into streams. In defining pollution the act stated, "Pollution shall be construed to mean noxious and deleterious substances rendering unclean the waters of the Commonwealth to the extent of being harmful to public health, or to animals or aquatic life, or to the use of such waters for domestic water supply, or industrial purposes, or recreation."

The Legislature of 1945 passed an act which amended the act of 1937, particularly with respect to industrial wastes. The older act specifically exempted acid mine drainage and coal mine silt from its provisions until practicable means for treating these wastes became known. The present act removes the exemption from silt, and the anthracite operators are preparing plans and instituting work on a large scale to comply with the law.

From 1937 to 1941 the Sanitary Water Board was largely engaged in a survey of 100,000 miles of streams and waters of the State to ascertain the extent of pollution from sewage and industrial wastes. The war interfered with this work but progress was made in preparing engineering plans for postwar construction. In 1944 a number of public hearings was held in several central cities, at which the Secretary of Health notified the municipalities of their obligation not to discharge untreated sewage. Following these hearings the Board began to issue letters to municipalities informing them of their responsibilities. Some 400 communities have by now been directed to prepare plans for appropriate sewage treatment works.

The 1945 Legislature also passed acts broadening the law concerning the incorporation of municipal authorities for financing sewage treatment, and permitting grants of up to 50 per cent of the cost of preparing plans for treatment works. In addition the Legislature ratified the Ohio River Valley Sanitation Compact, which will become effective upon ratification by Virginia.

"Economically sound expenditure of funds for sewage works requires much official and engineering planning. There is no present priority on this kind of work, and no substitute for the time it takes to do it. Following the war, construction may take place in an orderly way. The whole work is no longer a matter of opinion—the law provides that you should submit plans and proceed with abatement."

Abstractor's note. The author is Dean of the Schools of Engineering and Mines, University of Pittsburgh, and a member of the Sanitary Water Board. This article was prepared from an address to Allegheny County officials.

Richard D. Hoak

LETHAL EFFECT OF CHEMICALS ON FRESH WATER FISH

By N. H. Sanborn

Food Packer, 26, 40–4 (July, 1945)

The toxicity to fish (goldfish, large mouth bass, and "bluegill sunfish") of chemicals used for waste treatment in the canning industry and lye peeling operations was studied. The minimal critical concentration for sodium hydroxide, calcium hydroxide and ferrous sulfate was found to be 100 p.p.m., for sodium carbonate 200 p.p.m., for aluminum sulfate 250 p.p.m., and sodium nitrate 2000 p.p.m. The tests were made in water having

64–80 p.p.m. total hardness and a pH of 7.2 to 7.6. The maximum period of exposure of the fish to the chemical solutions was seven days.

It is stated that the experimental conditions set up in these tests are more rigorous than actually occur in practice. It is claimed that, on the basis of analyses of cannery wastes, it is apparent that the actual concentrations of the chemicals in a receiving body of water, even at a very low dilution ratio of 1 part waste to 2 parts receiving water, would be below the critical concentration to the species of fish tested, and therefore not inimical to their existence.

WILLIS M. VAN HORN

SOME RISKS OF TRANSMISSION OF DISEASE DURING THE TREATMENT, DISPOSAL AND UTILIZATION OF SEWAGE, SEWAGE EFFLUENT AND SEWAGE SLUDGE

BY H. WILSON

Preprint of a Paper Presented to the South African Branch of the Institute of Sewage Purification and discussed at the Metropolitan and Southern Branch of the Institute, June 9, 1945.

This is a rather comprehensive review of the literature pertaining to the transmission of various kinds of diseases by sewage, sewage effluents and sludge. It presents the evidence, opinions and information regarding transmission of diseases. It calls attention to the confused status and lack of uniform regulation in different countries and within the different states in the United States. The author has reviewed the literature within the past 70 years.

During the past epidemics of cholera and typhoid, sewage farms treating unoxidized sewage have not been danger spots.

The evidence and experimental work shows that the free swimming embryos of the eggs causing Bilharzia are destroyed within 24 hours and that entozoal forms of the life are not found in sewage farms, and Bilharzia is not disseminated by the distribution of sewage on land. The eggs are removed and retained in the sludge. A few of the embryos released from the eggs may pass through the biological filters. There are so many adverse conditions in sewers, sewage treatment plants and on farms that the danger of surviving cercariae reaching a human being is remote. Bilharzia is restricted to tropical and subtropical climates.

Eggs of the intestinal parasitic flat worms can survive for a long time in sewage, sewage sludge and polluted water and in localities where the incidence of the disease is high, sewage farms may accumulate large quantities of the eggs, and cattle grazing in sewage farms may become infested with the cysts. Infected cattle develop an immunity against tapeworm, and it is suggested by certain workers that cattle on sewage farms should be deliberately fed with a dose of eggs and kept for 2½ to 3 years after which they would have recovered and become immune. The author, however, states that where the incidence of the disease is high, sewage and sewage sludge present a real danger.

Hookworm also presents a danger wherever temperature and humidity are favorable for its development. The larvae of hookworm can exist in the warm damp soil for more than two years, but cannot survive prolonged desiccation.

Of the protozoan diseases, amoebic dysentery is very widespread and presents a danger in sewage disposal plants. It is in the cyst form that the *E. histolytica* is most resistant. It is estimated that 10 per cent of the population of the United States is infected by this organism. The cysts survive a long time in water. The survival time is longer at lower temperatures. They are killed at a residual chlorine concentration of 3 p.p.m. in 30 minutes. Fine sand filters remove 99.9 per cent of the cysts. Outbreaks of amoebic dysentery have been attributed to the consumption of inadequately washed salad vegetables grown on land which had been fertilized by manure containing raw human excrement. Primary settling tanks do not remove the cysts of *E. histolytica*. The cysts

of the amoeba and helminth ova may pass through trickling filters and survive the activated sludge process. Chemical precipitation and intermittent sand filtration remove the cysts. While *E. histolytica* cysts do not survive digestion, ascaris and hookworm ova are found after digestion and drying on sand beds.

Of the bacterial diseases cholera is known to be spread by polluted water, but the author could find no record of definite outbreaks of cholera attributable to properly managed sewage purification plants. The Southampton epidemic of 1866 was attributed to infected droplets of sewage in the air.

The typhoid bacteria can survive in sewage. MacConkey concluded from experimental work in 1902 that sewage and effluents from septic tanks, contact beds and trickling filters are inimical to the growth of *B. typhosus* and there is no multiplication in such environments.

The outbreak of enteric fever at Malton (Yorks) in 1932 was definitely traced to the unsterilized discharge of the excrement of a typhoid patient in a hospital. It was found that the drain from the hospital block had a leak which found its way into the well. By the time samples were taken from the well, *B. typhosus* could not be found in the water.

The paratyphoid outbreak at Epping, England, in 1931 has been extensively studied by the Metropolitan Water Board in order to safeguard the portion of London's water supply which was endangered by the discharge of the effluent from Epping into the stream which finally entered the London water supply. The Epping sewage contained up to 3,000 B. paratyphoid per cc. and the effluent 355 per cc. From one carrier case in Epping 450 million paratyphoid organisms per gram of feces was recovered.

In 1941, 65 cases of paratyphoid and typhoid occurred in the City of North Battleford, Sask. The cause was not conclusively determined but was suspected to be vegetables which had been irrigated and washed before sale with water from a ditch receiving sewage effluent.

Houston found viable anthrax spores in the septic tank and coke filter bed at Yeovel, which had not received sewage for three months. Yeovil is a center for skin dressing.

The virus of poliomyelitis has been found in sewage repeatedly, but only one case in which the virus has been found in drinking water. A well water subject to surface contamination was suspected to be the cause of infection in this case. The dosages of chlorine required to eliminate the virus are beyond practical limits—0.5 p.p.m. not being effective.

Bacteriophages capable of destroying some of the pathogens which may find their way into sewage are present in sewage and this suggests one reason why such pathogens diminish so rapidly in sewage purification plants.

The author draws the following conclusions on the basis of available evidence: (1) Pathogenic micro-organisms and the eggs and larvae of disease causing parasites survive in sewage and sludge for some time but do not multiply because of the inimical conditions.

(2) A progressive diminution of all forms of bacteria takes place as sewage passes through sedimentation tanks, filter beds, aeration tank units, final sedimentation tanks and straining filters or land treatment areas. The reduction of pathogenic organisms is of the same order as the reduction of all types of bacteria.

(3) There is, however, a concentration of all types of bacteria including pathogens and eggs and ova of parasites in the sludge.

(4) The danger from pathogenic bacteria and animal parasites is in proportion to the numbers present in the original sewage. In other words where the infection by pathogenic organisms is massive, as in times of epidemics, the danger of the survival of some of them and subsequent transmissions to humans is greater. Where a locality is free from any of the diseases, the danger from sewage is negligible and, under such conditions, there need be no restrictions on the use of sewage or sludge for manuring crops of all kinds. For years after an epidemic the sewage from a town may be dangerous. Five years after the epidemic at Epping, paratyphoid organisms were found in the sewage due to missed mild cases and carriers.

(5) All hospitals should sterilize the discharges from typhoid and other infectious cases.

The local Public Health Authority, having knowledge of the epidemics and the sanitary conditions and habits of the population, should have the power to issue restrictive regulations on the use of sewage effluent and sludge which should be exercised with full power during an epidemic emergency and relaxed when the danger is passed. The restriction may vary from the use of sewage and sludge on crops that are cooked, to grain crops, citrus fruit and other fruit trees, to crops used for only animal food. Total restriction of sewage or sewage products for raising any crop whatsoever is rarely justified except as a temporary measure in some grave epidemic.

The author considers the irrigation with raw sewage as objectionable and dangerous. If such sewage is used for irrigation, it should not be permitted on crops used for human and animal consumption or at least should be restricted to fruit and berry crops not wetted by sewage. The use of settled sewage for irrigation, despite the fact that the numbers of some of the pathogenic organisms are somewhat reduced, should still be considered dangerous and classed with irrigation with raw sewage.

The effluent obtained from trickling filters or the activated sludge type of plant followed by sand filtration should in a town free from endemic disease or no cases of disease for several years be regarded safe for irrigation of any type of crops except salad crops which are eaten raw. Some authorities have taken the view that for salad crops drinking water standards must be demanded. The author disagrees with this viewpoint because even with such precaution, chances of contamination from soil fertilizer flies and birds cannot be prevented. Regarding sterilization of effluents with chlorine to render them safe for irrigation the author considers it unjustified except as an emergency measure because of the cost. The author also uses the argument that such sterilized effluents when recontaminated become more favorable media for multiplication and hence more dangerous.

Any wells sunk in the vicinity of sewage farms or of a stream into which unsterilized sewage effluent is discharged must be regarded as dangerous. Normally infiltration through a few score of feet of soil sand, gravel or sandstone will suffice to filter out bacteria except when fissures exist.

In sewage farms, pools should not be left to allow multiplication of mosquitoes or other insects.

Because of the greater concentration of pathogenic organisms in sludge, it presents a greater danger than sewage. The conclusions drawn by Firth and Horrocks in 1902 are given. Enteric bacillus when placed in soil does not multiply or move in any direction, but it can be washed down at least 18 inches of soil by water, even when the soil is well packed and has no fissures. In some cases enteric bacillus has been recovered from soil even after 74 days. The survival of this organism is independent of organic nutritive material in the soil. Moisture content, however, is the dominant factor determining the survival, being longer in dry sand than in moist sand. The disappearance in moist sand is attributed to the washing down of the organisms to deeper layers. Enteric diseases can be transmitted from dried soil by means of wind and air currents. The organism is able to survive on the surface of soil to an exposure to 122 hours of direct sunshine.

Drying of sludge and storage at ordinary temperatures is not an adequate safeguard. If the sewage is heavily infected then the sludge derived from it should be considered dangerous since, in spite of the great diminution in number after treatment, there may be sufficient numbers left to infect crops grown and eaten uncooked. Chemical treatment of sludge to render it safe is considered out of the question because if completely disinfected to destroy harmful bacteria, the fertilizer value of the sludge is impaired. Heat treatment of either wet sludge or as a part of drying process is called for. Composting under conditions where the temperature rises to over 160° F. should render harmless sludge which has been infected. In order to accomplish this, the moisture content of raw or digested sludge should be reduced by some means to about 30 per cent. Ashes or soil to take up the excess moisture prevent the elevation of the temperature to 150° F. in all parts of the compost. To insure such elevated temperature the author suggests the use of mechanical mixing and artificial heating.

Frankland's conclusions in connection with the dissemination of air borne infection from sewers and sewage treatment plants are as follows: (1) Moderate agitation

of a liquid does not cause the suspension of liquor particles capable of transport by air. (2) The breaking of minute gas bubbles on the surface of a liquid is a potent cause of the transportable liquid particles in the air.

Some authors subsequently claimed that sewer air contained fewer bacteria than external air and others came to the conclusion that specific bacteria in sewage may be ejected into the air. In 1906 Delepine conducted careful experiments at a Manchester sewer and came to the conclusion that no material difference could be observed between animals exposed to sewer and to pure garden air and that in a well constructed sewer, the air is free from appreciable noxious properties. In sewers where deposition takes place the air becomes loaded with noxious gases. The garden air had only slightly fewer bacteria than sewer air and on some occasions actually more. The sewer where the experiments were conducted was fairly flat without undue turbulence or stagnation.

The author then discusses the question of grazing of cattle on sewage farms and points out court cases where sewage poisoning of cattle by drinking water from polluted waters has been claimed. The findings of Minett, Wooldridge and Sheather of the Research Institute of Animal Pathology Royal Veterinary College of London show that a milk cow which consumed 5,145 gallons of sewage in 21 months and for 11 months the animal drank nothing but undiluted sewage effluent gave no sign that the fluid was distasteful, thrived normally, increased in weight, gave birth to a healthy calf and yielded 1.8 gallons of milk per day. There is, therefore, no real reason for the belief of sewage poisoning or that there is a disease brought about by the consumption of sewage. Neither is there any foundation to the claim that milk from cows grazed on pastures irrigated with sewage results in the contamination of milk provided that animals are properly cleansed before milking. The two exceptions to the above statement are: (a) the ova parasites and (b) anthrax.

The author supports the view commonly held that in view of long standing practice of applying sewage, effluents and sludge on crops and the lack of definite evidence that such practice has resulted in any epidemic, the dangers of spread of disease cannot be really great. Only seldom can the produce raised on a sewage farm be more liable to danger than an ordinary farm product. However, it is the duty of a Public Health Officer to protect the public and take measures to minimize the dangers.

H. HEUKELEKIAN

THE BACTERIOLOGY OF ACTIVATED SLUDGE

BY L. A. ALLEN

Journal of Hygiene (London), **43**, 424–431, No. 6 (1944)

In an attempt to break up and disperse the bacteria in the floc and thereby obtain a more accurate count of the bacterial population of the floc, the floc was homogenized by a cream making machine by pumping the liquid through a narrow orifice. Ratios of numbers in homogenized to untreated activated sludge samples varies from 11:1 to 101:1. A maximum number of 2,200 million per ml. was obtained from a homogenized sample of activated sludge on nutrient agar. Passing the sample through the homogenizer up to five times increased the numbers. By using this method for dispersing the bacteria the numbers were estimated in the formation of activated sludge from sewage by aeration and thereafter by using the sludge produced to aerate fresh samples of sewage. The results indicated that the total numbers of bacteria increased during the aeration of sewage, the increase occurring after the beginning of aeration. A high total count was maintained for over 11 days. Even after the floc was formed during the aeration of sewage there was still a large number of bacteria in the supernatant liquid. When the sludge formed was used for aeration of sewage an increase in bacterial count again occurred but in this case the bacteria associated more quickly with the sludge, thus having fewer in the supernatant liquid. Aerobic and anaerobic spore forming bacteria were present only in small numbers. Coliform bacteria, although present, represented

only a small fraction of the total flora at any stage. Of the various types of nutrient media employed, none gave counts higher than the nutrient agar. It is to be noted that homogenization process probably did not completely disperse all the bacteria into individual cells and therefore the actual numbers are probably higher than obtained. Since the concentration of the solids in the sludges are not given, it is not possible to convert the values on the basis of dry matter nor compare the values from one sludge with another.

The characters of the predominant bacteria in activated sludge produced in the laboratory and obtained from plants by using the homogenization technique were studied. All the species isolated were rod forms. Most of them were gram negative, nonspore forming types and had no action on sugars. These general characteristics indicate that they are water and soils types and would be classified as genera of *Achromobacterium, Chromobacterium* and *Pseudomonas*. The tendency of the flora is to change from nonproteolytic to proteolytic types when the sludge changed from the early period of formation to the period when it had been in use for some weeks. This is attributed to the paucity of proteins in the initial sewage sludge mixture which later increases due to the formation of bacterial cells.

H. HEUKELEKIAN

INVESTIGATIONS INTO THE FLY POPULATIONS OF PERCOLATING FILTERS

BY T. G. TOMLINSON AND G. O. STRIDE

Preprint of a Paper Presented to the Northeastern and Northwestern Branches of the Institute of Sewage Purification at Southport, July 18, 1945.

This paper is based on observation of fly trappings made from filters at the Minworth Works of Birmingham, Tame and Rea District Drainage Board as well as ten works in the Manchester District. Altogether the following species were found: *Psychoda alternata, Psychoda severini, Psychoda cinerea, Spaniotoma minima, Spaniotoma perennis, Metriocnemus hirticollis, Metriocnemus longitarsus, Anisopus cinctus, Spathiophora hydromyzina, Limnophila ferruginea, Leptocera fontinalis, Cercyon ustalatus.* The average for all the filters studied gave the following distribution of numbers: *Psychoda* spp. 745, *Spaniotoma minima* 33, *Metriocnemus* spp. × *Spaniotoma perennis* 11, *Anisopus cinctus* 11, and *Spathiophora hydromyzina* 1. The average numbers of flies from 10 filters (single stage) showed that *Psychoda severini* occurred in greatest numbers in April, May and June; *Psychoda alternata* in August; *Anisopus cinctus* between April and July; *Spaniotoma minima* from August to October, *Spaniotoma perennis* in April, May, September and October; and *Metriocnemus* spp. in late May and early June. Although the average numbers are not as important as the peak emergence, results show that there is a direct linear relationship between the average number caught and the per cent of the number of occasions when an arbitrary peak of numbers in excess of 2,000 were trapped.

The relationship between loadings on 17 single stage filters and numbers of flies trapped were studied. The results showed that the numbers of *Psychoda* increased with filter loading (expressed as lb. B.O.D. per acre per day the values ranged from 500 to 3,000). The amount of film also increased with the filter loading (expressed both as lb. B.O.D. per acre per day or lb. volatile solids per acre per day applied). No *Spaniotoma minima* were trapped with filter loading greater than 2,000 lb. B.O.D. per acre per day. Filters with large numbers of *Psychoda* produced very few *Spaniotoma minima. Metriocnemus* spp. and *Spaniotoma perennis* were more numerous in lightly loaded filters with small quantities of film. There was no simple relationship between the numbers of *Anisopus cinctus* and filter loading. In the majority of filters more *Psychoda* emerged from coarser sized filtering media than from the finer media. At Minworth two filters operated in the same way but with media of different sizes, a direct comparison showed that the filter with media 95.5 per cent of which was over ¾ in. produced more

Psychoda than the filter in which 68.7 per cent of the media was over ¾ in. The numbers of *Anisopus* were equal in the two filters. *Achorutes viaticus* was observed to be more abundant in filters with fine medium than in filters with coarse medium.

Comparisons were also made of the number of flies from single stage filters operated at about 60–80 gal. per cu. yd. per day and the alternating double filters operating at rates varying from 160 to 300 gal. per cu. yd. per day. These experiments covered a period from 1941 to 1944. Fewer *Psychoda* and *Anisopus* emerged from alternating double filters than from a single filter in proportion to the amount of sewage treated. More flies emerged from the filters after a week in the secondary position than after a week in the primary position. This was due to the fact that when the filter was in the primary position the film tended to close the spaces between the stones and impeded the emergence of flies. The film was broken down when the filter was put in the secondary position.

H. HEUKELEKIAN

EFFECT OF DRYING AND DIGESTION OF SEWAGE SLUDGE ON CERTAIN PATHOGENIC ORGANISMS

BY E. J. STOKES, E. E. JONES AND A. A. MILES

Preprint of a Paper Presented at the Meeting of the Metropolitan and Southern Branch of the Institute of Sewage Purification in London, June 9, 1945.

This work was undertaken as a result of greater use of sludge as fertilizer in England during the war, at the Public Health Laboratory of the Emergency Pathological Services and the Water Pollution Research Laboratory. The purpose was to ascertain the viability of certain pathogenic bacteria during drying and digestion of sludge.

Large numbers of pathogenic bacteria were added from cultures into primary sludge and allowed to digest and dry on small experimental sludge drying beds. The beds contained 11 in. of draining material, the bottom of which was coke and the top coarse sand. The sludge depth was 6 in. The pathogenic organisms recovered were identified by chemical and serological reactions. The pathogens used could not be counted by selective media. Preliminary enrichment methods were used to enhance the growth of pathogens, the presence or absence of which was determined in 0.1 gram of dry sludge samples. *Bact. paratyphosum B* was recovered from sludge by inoculation into tetrathionate broth and subcultured on eosin brilliant green methylene-blue agar.

In the first experiment the drying bed was filled with liquid sludge to which had been added a heavy inoculum of *Bact. paratyphosum B* (25 million per ml. of sludge). During 48 days of drying there was considerable reduction in organic matter as indicated by the decrease in ash from 75 to 48 per cent. Difficulty was encountered in the isolation of *B. paratyphosum B* because of the overgrowth of plates by *Proteus vulgaris*. Negative results were obtained (absent in .1 gm. of dry sludge) after 2 days of drying but positive results were obtained thereafter from the 9th to 27th day. On the 41st day of drying, the results became negative again.

In the next experiment *Bact. typhi murium* was used. This organism was recovered by inoculating 1 ml. of sludge into tetrathionate broth and then transferred to eosin brilliant green methylene-blue agar. The organism could be recovered by this method when the concentration of viable organisms was 50 per ml. of sludge. The initial inoculation was equal to 7.5 million organisms per ml. of sludge. After 135 days of drying the sludge contained 40 per cent dry matter, and after 180 days 86 per cent (the experiment was conducted from December to June). *Bacterium typhi murium* could be isolated from .1 gram dry sludge after 180 days of drying.

In the next experiment the viability of *Bact. typhi murium* was studied during anaerobic digestion. The fresh solids were mixed with ripe sludge and inoculated with 57 million organisms per ml. of sludge. The organism was recovered in 1 ml. portion

of the sludge throughout the digestion period of 45 days. The total numbers of all types of bacteria diminished progressively. The decrease in the yield of *Bact. typhi murium* was roughly parallel with that of the total flora.

A number of partially dried sludges obtained from different sewage works was examined. In all, 33 samples were examined from plants receiving domestic sewage. Three of the samples were obtained from districts in which typhoid epidemics had occurred within the last few years. Three ml. samples of diluted sludge containing 10 per cent solids were examined. No bacteria of pathogenic character were isolated from any of the samples of sludge examined.

H. HEUKELEKIAN

BOOK REVIEW

Piping Handbook. By SABIN CROCKER. McGraw-Hill Book Co., Inc. Fourth Edition, 1945. Price, $7.00.

A handbook of 1,350 pages, comprising 18 chapters, as follows:

	Title of Chapter	*Pages*
I.	Definitions, Formulas and Tables	26
II.	Fluids—Properties of Fluids	274
III.	Metallurgy of Piping Materials	47
IV.	Pipe, Valves and Fittings	346
V.	Heat Insulation	27
VI.	Hangers and Supports	133
VII.	Expansion and Flexibility	107
VIII.	Steam Power Plant Piping	79
IX.	Building Heating Systems	35
X.	Plumbing Systems	28
XI.	Underground Steam Piping	20
XII.	Water Supply Piping	66
XIII.	Fire Protection Piping	17
XIV.	Oil Piping	57
XV.	Gas Piping	53
XVI.	Refrigeration Piping	135
XVII.	Corrosion	34
XVIII.	Hydraulic Power Transmission Piping	65

This handbook, in its earlier editions, is well known to hydraulic engineers. The new edition is brought up to date in all parts but the expanded chapters on "Gas Piping," "Corrosion" and "Water Supply Piping" will prove of greatest interest to sanitary engineers.

Of particular interest to sewage works technicians will be the coverage afforded the "rational" or Reynolds number type of solution for fluid-flow problem. The analysis is applicable to the design of all types of piping for the handling and transportation of sewage sludge.

Beyond the elementary flow formulas (Chapter II), clay and concrete pipe specifications (Chapter IV), brief reference to house waste services (Chapter X) and a presentation of the Marston analysis of earth loads on pipe in trenches (Chapter XII), the book does not include information on piping problems associated with the design of public sewer systems. The material on water, sludge, gas and air piping is sufficient, however, to make the handbook invaluable to sewage works designers, in the solution of the diverse and complex piping problems involved in such works.

W. H. WISELY